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This Volume of

# SOIL SCIENCE

is dedicated to

DR. JACOB G. LIPMAN

FOUNDER OF THIS JOURNAL AND ITS
EDITOR-IN-CHIEF FOR 20 YEARS

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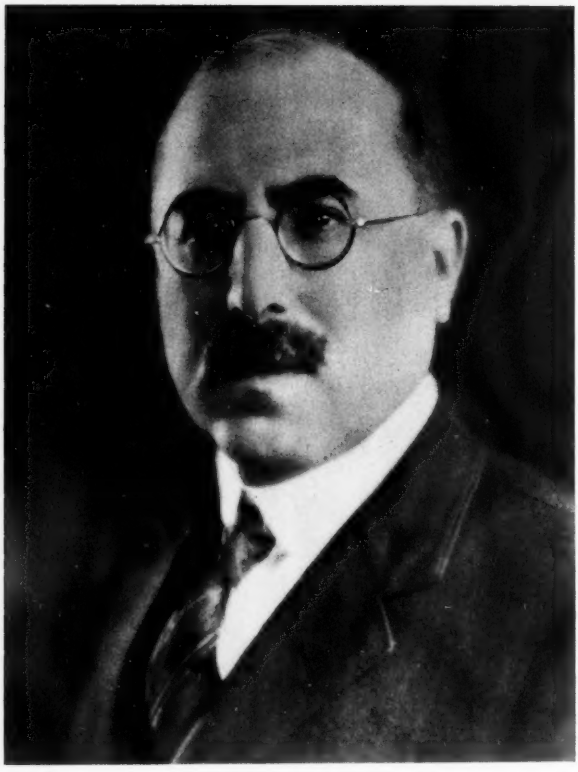

JACOB GOODALE LIPMAN

UNIV. OF MICH.

In his absence on sabbatical leave, 1934–1935,
the advisory staff of SOIL SCIENCE takes the opportunity
to dedicate volume 40 of the journal, and especially this number
To
DOCTOR JACOB GOODALE LIPMAN
in honor of his twenty years of editorship
and his long continued service to soil science and agriculture.

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# JACOB GOODALE LIPMAN

## Biographical Sketch

Jacob G. Lipman was born in Friedrichstadt, Russia (now Latvia), on November 18, 1874. He received his early education under private tutors in Moscow and later in the gymnasium of Orenburg. In 1888 his family emigrated to the United States and settled very soon afterward on a farm at Woodbine, New Jersey. While assisting his father in caring for the farm, he became interested in the scientific principles underlying agriculture. This led him to become a student of Baron de Hirsch Agricultural School in Woodbine, where he was trained both in practical methods of farming and in certain fundamental principles. The knowledge thus gained did not satisfy him; consequently, upon graduation from the school in 1894, he entered Rutgers College. Here he had an opportunity not only to study the arts and sciences, but, under the inspiring influence of one of his teachers—Professor E. B. Voorhees, an outstanding leader in this country in the field of research in soil and fertilizer chemistry—he decided to devote his future life to this subject. Upon graduation from college in 1898, he went to Cornell University for advanced training in chemistry and in bacteriology; he was at first appointed graduate scholar at that institution, and later, Sage Fellow in Chemistry. He obtained his master of science degree from Cornell in 1900 and his doctor of philosophy degree in 1903. In 1901, he was called back to New Jersey by his former professor to establish a department of soil chemistry and bacteriology at the Agricultural Experiment Station. In 1902 he was appointed instructor in agricultural chemistry at Rutgers College; in 1906 he was made assistant professor; and in 1910, full professor. In 1915, he was made dean of the College of Agriculture. Four years previously, upon the death of Professor Voorhees, he became director of the Experiment Station.

Doctor Lipman has lectured at a number of universities and other institutions in this country and abroad. He is a member of numerous scientific societies and an honorary member of several foreign academies. He holds honorary degrees from different universities and special medals from various scientific societies. He has served on a number of important committees, such as the National Committee on Soil Erosion and various committees of the National Research Council and of the American Society of Agronomy. On several occasions he has acted as special representative of the United States at the International Institute of Agriculture in Rome. He took an active part in the organization of the International Society of Soil Science. At the Prague Conference, he was elected joint-president of the Third Commission on Soil Biochemistry and Bacteriology, and participated actively in the preparation

of the program of this commission for the next conference, which took place in Rome in 1924. At that conference he was elected president of the newly formed International Society of Soil Science. He organized the First International Congress of Soil Science in 1927, in Washington, D. C., which was followed by a special scientific excursion throughout the United States and Canada. In 1929 he received one-third of the first Nitrogen Research Award, made by the Nitrate of Soda Committee of the American Society of Agronomy. He contributed this award to a special fund for furthering soil science at the New Jersey Agricultural Experiment Station. A number of individuals and societies in the state made similar contributions, and the fund became known as the Cook-Voorhees fund, in honor of the first two directors of the New Jersey Experiment Station, prominent in the field of soil science in their own days. This fund is used for assisting foreign scholars who plan to come to the institution for carrying out special investigations in one of the various phases of soil science.

Before the World War, the scientific workers in the United States depended, for necessary scientific literature, upon foreign journals, largely those published in Germany, France, and Great Britain. One of the direct results of the war was to make the United States independent of Europe in this respect. A large number of journals in almost every branch of science were established. Among these, SOIL SCIENCE made its appearance in January, 1916. The first issue of this journal was dedicated to E. W. Hilgard, one of the greatest minds in the field of soil science. The journal was first published by Rutgers College. At the end of the third volume, however, it was taken over by the Williams and Wilkins Company of Baltimore, Maryland, and has been published by them uninterruptedly under the editorship of Doctor Lipman. From the beginning, the pages of the journal have been open to workers in soil science in this country and abroad.

This year of his sabbatical leave from the College and Experiment Station is the first time that Doctor Lipman has relinquished, even temporarily, the duties of active editor of the journal. The Editorial Committee takes this opportunity of commemorating the twentieth year of publication of SOIL SCIENCE by dedicating this fortieth volume of the journal to its Editor-in-Chief.

In dedicating this volume to Doctor Lipman, the Editorial Committee can pay no higher tribute to him than that which he himself paid to Doctor Hilgard twenty years ago when he said:

"... while the world of science knew of his work and honored him for it, it was the peculiar privilege of his associates to find inspiration in his kind and helpful nature, in his catholic sympathies, in his clear vision and in his unfailing devotion to truth."

# JACOB G. LIPMAN AND SOIL SCIENCE

E. J. RUSSELL

*Rothamsted Experimental Station, England*

There are two ways in which a man may advance science: by his own personal investigations, and by organizing and otherwise facilitating investigations of others. In the usual course a man begins as an investigator; then he is promoted to take charge of his section or department, when he has to lead his team of assistants and students; finally he is entrusted with the care of an entire institution, when he has to maintain its interests in the face of a sceptical and sometimes hostile world—in any event, a world full of noisy claimants for popular favor. And, since nothing succeeds like success, he must ensure success by keeping the whole program as well balanced as possible and helping all departments in their endeavors for advancement, favoring none, repressing none.

Doctor Lipman followed the usual sequence and he has been eminently successful in all the parts he has been called upon to play. There are some who rank as administrators among men of science, and as scientists among administrators. Doctor Lipman, however, is recognized by administrators as a particularly shrewd and able administrator and by scientific workers as a pioneer investigator in soil microbiology. Under his guidance the New Jersey station has always maintained a good level of scientific and practical achievement. It has had no intellectual misfortunes, no "discovery" that had afterwards to be withdrawn because the experimental work was badly done or the deductions loosely drawn; its history has been a continuous record of steady progress in science and service to the community. His ability as an administrator has enabled him to dispense with the adventitious aids of advertisement: in consequence, one finds always at the station a peaceful atmosphere conducive to scientific thought and quiet reflection, perhaps the most important factor in promoting research. "Das dauernde Nachdenken und Durchdenken jeder einzelnen Erscheinung in dem Ackerbau führt immer zu etwas," wrote Liebig to Wöhler in 1862—prolonged meditation and pondering about any agricultural phenomenon is bound to lead somewhere—and the wide open space of the campus, adorned with water and with trees slowly growing into a haunt of ancient peace, shows how Doctor Lipman has striven to satisfy this need for quiet thinking, for the unhasting, unresting endeavor toward higher fields of scientific thought and activity.

He began his work at a critical period in the history of agriculture. The new science of bacteriology, just being applied to agriculture, had revealed a new and hitherto completely unexpected world of life—living organisms so small

and yet so numerous that the mind utterly failed to grasp the figures expressing either their size or their number. Astronomy alone could furnish parallels, and men's minds moved in contemplation from the Infinitely Great to the Infinitely Little, lost in wonder and in admiration at the new marvels disclosed by science. In the agricultural laboratories the achievements of Winogradsky, Beijerinck, Warington, and others had shown a wonderful picture of soil life, rousing the imagination and stimulating the scientific interest of many of the younger workers of the day. They had used culture methods, in the main the elective methods, excluding all organisms but the one under investigation and they had achieved marvelous results. Doctor Lipman began also by using these methods to study a question which was then causing considerable commotion in agricultural circles, the loss of nitrogen from farmyard manure. This had always been regarded by practical men as the ideal fertilizer, and the battle of the giants of those days raged about the question: farmyard manure versus artificials. Then farmyard manure was shown to suffer great loss easily, and worse still, to make even artificial fertilizers, especially nitrate of soda, suffer loss also. Great was the perturbation when the German chemists Wagner and Maercker first announced this: Warington at Rothamsted immediately took up the cudgels and showed that the result, as far as farmyard manure was concerned, was obtained only under abnormal conditions never likely to arise in practice. Nevertheless, loss of nitrogen in other ways was sufficiently serious to demand the fullest investigation. The process was called "denitrification" because, being a decomposition of nitrates, it was the reverse of nitrification, and it was soon attributed to bacteria; it was anaerobic and required the presence of organic matter. In studying some of the organisms concerned, Doctor Lipman broached two subjects which have since developed greatly: the importance of joint action or symbiosis of the soil organisms, and the relation between denitrification and the composition of the organic matter concerned, now commonly referred to "as the influence of the carbon/nitrogen ratio," though he did not then put it in that way.

Almost immediately, however, he turned to another subject which had long puzzled scientific workers: Where does the nitrogen of the soil come from? For a hundred years chemists had looked upon nitrogen as the embodiment of inertness, unable to enter into chemical combination or to sustain life: the French, logically minded always, called it "azote"—without life. It was true that some misguided young person had shown how to make it combine with certain metals, forming nitrides, but these compounds, falling outside the recognized lines, were very properly ignored by self-respecting teachers and by the framers of examination syllabuses. Berthelot had suggested that it might be assimilated by certain bacteria but he gave no proof; the idea was regarded as one of those bright thoughts that may be put forward by a man of genius and established reputation, but that need not be taken too seriously. Then, like a bombshell, came Hellriegel and Wilfarth's discoveries that certain microorganisms associated with leguminous plants certainly could assimilate gase-

ous nitrogen, and finally Winogradsky's and Beijerinck's discoveries of organisms which could fix nitrogen independently of higher plants. Beijerinck's organism was called "Azotobacter," and was particularly interesting. It could not, in his view, find nitrogen by itself—it needed the help of other organisms—but it had the power of setting in train the chain of processes which began with the taking up of nitrogen and ended with the synthesis of protein. Chemists could by this time reproduce the first stage: they could fix nitrogen with the aid of elaborate appliances, high tension electricity, and high temperatures, but they could get no further than nitrate or ammonia, and even yet cannot begin to approach a protein synthesis. Yet here was a lowly organism completing the whole process without appliances, electricity, or extra heat. The organism and the process were alike of fascinating interest and attracted Doctor Lipman from the outset. He isolated, in all, four species —one might more properly say "forms"—of Azotobacter from New Jersey soils and showed also that they could fix nitrogen alone, unaided by other organisms: the power was therefore something inherent in this particular organism. This narrowed down the problem considerably, and others confirmed and extended the work. At the same time he showed that the power of fixation was enhanced by the presence of certain other organisms, one which he labelled "B 30" being a specially efficient partner although in itself unable to fix any appreciable quantity of nitrogen. Not all organisms, however, increased the amount of fixation; some actually depressed it. Again, therefore, he had evidence of the profound effect of joint action. He argued that it is unsafe "to judge of bacterial processes in the soil from a one-sided study of the behavior of single species in certain culture media. Under actual conditions, the modifying influences are very numerous and variable, hence the need of studying carefully not only the *pure* cultures, but also the mixed cultures, but under conditions susceptible of control."

Always practical in his outlook, Doctor Lipman early raised the question: What has all this to do with soil fertility? Are soil microörganisms concerned in the process to any importance? If so, how, and how can we measure their effect? He saw too that a valuable measure, if it could be obtained, would be the rate of ammonification of added organic matter: he could thus obtain information about both soils and organic manures.

For this type of work, however, it was necessary to deal with the soil itself. He thus had the courage to break away from the methods of pure culture and the single organism in spite of the important results they had been giving. He had realized, and he was one of the first to do so, that the soil microörganisms probably form a population, a group with certain permanent, recognizable characteristics, and that the surest way of studying their relation to crop production was to study them in the soil itself. Hence the tumbler method, one of the simplest and most useful methods that could be devised. It gave no startling results, nor was it expected to do so, but it opened the way to much new knowledge about the decomposition processes in the soil and their connection with the growth of plants.

The influence of the composition of organic matter on its rate of decomposition in the soil continued to attract him: in 1907 he pointed out the desirability of adding nitrogen as nitrate after ploughing in green manure in order to hasten the decomposition.

He studied also the relations of bacteria to another element, sulfur. Few people would believe that bacteria could oxidize sulfur to sulfuric acid, but in the New Jersey laboratories it was shown that this actually happened. This found interesting application as a means of controlling soil reaction: it had always been possible to make an acid soil neutral by means of lime, but only one method was known for making a neutral soil acid or an alkaline soil neutral, and that was by prolonged use of sulfate of ammonia without lime. The need for acidification came later into agricultural chemistry; it appeared in two forms: in dry regions to make an alkaline soil neutral, and in wet regions to make a neutral soil intended for potatoes slightly acid so as to put the "scab" organism out of action. The application of sulfur was both practicable and convenient and it has been frequently adopted.

All this time there were continuing at the New Jersey Station the cylinder cropping experiments begun by the late Doctor Voorhees for the purpose of giving some quantitative information about the relative effects of different nitrogenous fertilizers on the more common crops of the region. Doctor Lipman kept up the quantitative form of the experiment; the produce was weighed and analyzed, the soil was periodically tested to see how far in practice the information given by the laboratory methods accorded with the field results. This close linkage of field observation and laboratory experiments has given a special stamp to the New Jersey cylinder investigations, and the data obtained are among the best on their subject. One of the most important deductions from this work is that the value of an organic manure depends not only on the state of combination of its nitrogen but also on its percentage of carbon. A high proportion of carbon tended to increase the number of bacteria and fungi so much that they used up the nitrogen themselves for their own food instead of leaving it as ammonia or nitrate to be taken up by plants. This idea has been extensively developed at New Jersey; it has explained many difficulties met with in field practice, and it helps the expert considerably in his task of assessing the values of the many organic manures now available.

Doctor Lipman's work has always been characterized by originality of outlook. His discovery that Azotobacter by itself can fix nitrogen is of historic importance, but equally valuable was his gradual recognition of the importance of the compositions of organic matter—its carbon-nitrogen ratio—on its decomposition in the soil. He also in the course of his work put out many suggestive ideas which others could work up, including the idea of a synthetic agar medium and a suggestion that Azotobacter could be used to estimate the available mineral food supplies in the soil: he recognized too, the importance of iron in the nutrition of Azotobacter. He exposed at least one false road and showed that it led nowhere—the idea that the nitrogen resources of the soil could be

increased by inoculation with cultures of Azotobacter. It had been a simple and attractive idea—men will always fall to the notion of getting something for nothing—but Doctor Lipman was not to be caught; he gave it a fair trial and showed that it was not a way of progress.

As a writer he has the invaluable quality of being able to express himself clearly, and in consequence his books, "Bacteria in Relation to Country Life" and "A Laboratory Guide in Soil Bacteriology" (jointly with P. E. Brown), and his contributions on soil bacteria in relation to soil fertility to Marshall's volume have been widely read.

His influence has not been confined to New Jersey. He was one of the first to recognize the new movement toward world coöperation in science, and he was widely acclaimed as the most suitable person for the presidency of the International Society of Soil Science when that body decided to hold its Congress, the first of the kind, in the United States. So successful was the Congress that the society decided to continue these meetings, and it now affords one of the best examples of the advantages of international coöperation. The movement is only in its infancy: its future is pregnant with possibilities of the greatest significance for the welfare of mankind. The name of Doctor Lipman, the first president, will always be remembered.

Doctor Lipman may well be proud of so great a record of achievements: his friends and colleagues certainly are, and we all unite in wishing him many years more of peaceful happy work at the station to which he has devoted his time, his thought, and his life.

THE CAMPUS OF THE NEW JERSEY AGRICULTURAL EXPERIMENT STATION

# JACOB G. LIPMAN AS AN INVESTIGATOR

## A Chapter in the History of Soil Microbiology

SELMAN A. WAKSMAN

*New Jersey Agricultural Experiment Station*[1]

### INTRODUCTORY

In the history of soil microbiology, the name of Dr. Jacob G. Lipman will always be connected with the study of the cycle of nitrogen in nature, especially the problem of nitrogen fixation by non-symbiotic bacteria, the liberation of nitrogen as ammonia in the process of decomposition of organic nitrogenous substances in soil, and the general relations of nitrogen liberation in soil to the growth of higher plants. His scientific activities began at a time when the importance of microörganisms in soil processes was receiving attention; among these processes none aroused greater interest than the rôle of these organisms in the cycle of nitrogen in nature in general and in the soil in particular. The epoch-making contributions of Winogradsky and Beijerinck were just becoming recognized, and it was Doctor Lipman who represented their school of thought in this country. In order, therefore, to understand the reasons that led him to become actively interested in the rôle of microörganisms in soil processes, it is essential to know the historical development of our knowledge of the science of the soil and its relation to agriculture in general and in this country in particular, at the time Doctor Lipman first entered the field of scientific research.

The last two decades of the nineteenth century marked the beginning of a new science, that of the bacteria in the soil. Minute microscopic organisms have become recognized as important agents not only in disease and numerous fermentations but also in the soil, taking part in a number of transformations that are essential for plant development. It was discovered that the soil was not an inert mass of inorganic compounds and of dead organic residues, but was teeming with life. The microscopic organisms which were found to inhabit the soil were shown to comprise numerous groups having highly specialized functions and participating in numerous soil processes. Among the outstanding contributions which loomed large and which have since become classics in the science of soil bacteriology, it is sufficient to mention the work of Robert Koch (1881) on the plate method, whereby it was made possible to determine the abundance of bacteria in the soil, and the investigations of Hellriegel and Wilfarth, Beijerinck, Schloesing, and Laurent on the rôle of bacteria in the

[1] Journal Series paper of the New Jersey Agricultural Experiment Station, department of soil chemistry and bacteriology.

fixation of nitrogen by leguminous plants. The extensive and painstaking studies of French, German, and English investigators on the agents responsible for the process of nitrification in soil culminated in the brilliant contributions of Winogradsky, who succeeded in isolating the nitrifying bacteria in 1891. This achievement was followed, in 1893, by his isolation of the first group of non-symbiotic nitrogen-fixing organisms, the anaerobic *Clostridium pastorianum*. Our knowledge of the process of ammonia liberation in soil through the decomposition of nitrogenous organic complexes by microörganisms had been enriched and firmly established by the work of Marchal and of Müntz and Coudon, in 1893.

Soon after it became evident that various specific bacteria are concerned with highly beneficial soil processes, Wagner announced (in 1895) that certain soil bacteria may also bring about extensive losses of nitrogen from the soil; when nitrates are introduced into the soil together with stable manures, they are rapidly destroyed, giving rise to gaseous nitrogen. Although the existence in the soil of bacteria capable of reducing nitrates (denitrification) was known during the previous decade, the rapidly increasing application to soils of inorganic fertilizers, especially of nitrates as nitrate of soda, immediately centered the attention of the scientific world upon this process as a possible danger to the most efficient utilization of nitrogen by growing crops. This claim of Wagner aroused considerable interest among the agricultural institutions in the United States and led directly to the establishment at the New Jersey Station of the first research project dealing with the bacterial population of the soil. The New Jersey Agricultural Experiment Station under the leadership of Doctor E. B. Voorhees, director and chief chemist, was already engaged in extensive studies on the influence of fertilizers, especially nitrogenous salts, upon plant growth. It was, therefore, logical that the study of the utilization of different fertilizers should lead directly to a study of the transformation of these compounds in the soil. In 1898, a series of investigations were begun on the changes that nitrogen undergoes in the soil; John P. Street was then appointed as associate chemist, to assist Doctor Voorhees in these studies. The very first experiments dealt with the reduction of nitrates in the soil, with the changes produced in the nitrogen in barnyard manure, and with the availability of the nitrogen in the liquid and solid portions of the manure, as compared with inorganic salts as sources of nitrogen for plant growth.

The 20th Annual Report of the Experiment Station, for the year ending October 31, 1899, contains a paper by Street (p. 86) on "The Reduction of Nitrates in the Presence of Barnyard Manure" and a contribution by Voorhees (p. 97) on "Investigations Relative to the Use of Nitrogenous Materials." These investigations were continued during the following two years, and the results were published in the 21st and 22nd Annual Reports of the New Jersey Station, which appeared October 31, 1900 and 1901 respectively. The latter report contains a paper entitled "A Review of the Investigations Concerning

Denitrification," in which a summary is presented of the current ideas in Europe and in this country on the reduction of nitrates in the soil.

In these first investigations, special emphasis was laid upon the chemical processes and upon the response of the growing plant. They were sufficient, however, to convince Doctor Voorhees that it was highly essential, in order to understand these processes, also to undertake a study of the microörganisms responsible for them, especially in connection with the cycle of nitrogen. A recent graduate of Rutgers College (Class of 1898) who was then carrying out graduate work in bacteriology at Cornell University, namely, Jacob G. Lipman, was invited to undertake these investigations, and, on July 1, 1901, he received the appointment of assistant in soil chemistry and bacteriology at the New Jersey Station. This appointment was made for the special purpose of studying "the movement of plant food in the soil, and the part of bacteria in the formation, change or destruction of such plant food."

The new assistant immediately set to work upon the problem assigned to him. Fresh from his work at Cornell University on methods of studying bacteria in general, he applied the information thus gained to the bacteria of the soil. His first investigation was reported the same year, in the form of a two-page paper published in the 22nd Annual Report of the Station (1901, p. 213–214). It described a sampling tube for taking adequate soil samples for bacteriological work. One year later, an extensive paper (23rd Annual Report for 1902, N. J. Agr. Exp. Station, p. 183–241) dealing with the morphology and physiology of denitrifying bacteria was published. This first important contribution of Doctor Lipman to the subject of the bacterial population of the soil and its relation to soil fertility shows a firm grasp of the literature, a critical attitude toward the subject under investigation, and an original method of approach. Several new cultures of bacteria were isolated and described. This paper, however, also tended to indicate that the problem of denitrification was not absorbing all the interest of the young investigator, but that another problem, namely, that of the bacteria concerned in the process of non-symbiotic nitrogen-fixation was also attracting his interest. This is shown by the fact that some consideration is given to this subject, even in this first paper, since a certain phase of the investigation deals with "The Fixation of Nitrogen by Denitrifying Bacteria."

## THE FIRST PERIOD, 1902–1911

Probably one of the most important scientific contributions, if not the most important contribution, ever made by Doctor Lipman is found in his second paper, published as the Report of the Assistant in Soil Chemistry and Bacteriology in 1903 (24th Annual Report, p. 217–285). This paper deals with "Experiments on the Transformation and Fixation of Nitrogen by Bacteria." A brief description of a newly isolated non-symbiotic nitrogen-fixing organism, *Azotobacter vinelandii*, as well as a preliminary description of several other organisms, was given. This material comprised a part of the thesis presented

in 1903 for the degree of doctor of philosophy at Cornell University. This work followed immediately upon the discovery by M. W. Beijerinck (1901) of the first aerobic non-symbiotic organism, *Azotobacter chroococcum*. This group of organisms, comprising the genus Azotobacter, has since become recognized as one of the most important members of the soil population. Although Beijerinck was the first to isolate a representative of this group, he did not recognize the fact that this organism can fix large quantities of nitrogen in the absence of any other bacteria. Lipman not only isolated the second important member of the group, but he was also among the first to prove beyond any doubt that these bacteria are capable of fixing large quantities of nitrogen obtained from the atmosphere, even in pure culture, using various forms of carbon as sources of energy.

The following year marks the promotion of Doctor Lipman at the New Jersey Station from the position of assistant to that of soil chemist and bacteriologist. The report of the investigations carried out during the year ending October 31, 1904 (25th Annual Report, p. 237–285) contains his paper "Further Contributions to the Physiology and Morphology of Members of the Azotobacter Group." This report is preceded by a detailed survey of the status of soil bacteriology in general. Two new species of Azotobacter are described; namely, *Az. Beijerinckii* and *Az. Woodstownii*. A detailed study is now presented of the physiological activities of the genus Azotobacter. The investigation of the influence of reaction upon growth of this organism revealed the fact that the negative results previously obtained by Beijerinck concerning the ability of Azotobacter to fix nitrogen in pure culture were directly due to the acidity of the medium employed by Beijerinck. When the medium was properly buffered, positive fixation was definitely obtained. The first thermochemical considerations of the mechanism of nitrogen fixation are also found in this paper. An attempt was made to inoculate the soil with Azotobacter, but the results obtained were entirely negative: no gain in nitrogen could be demonstrated in the case of the inoculated soil. It should be noted here that this particular problem is still receiving considerable attention, and the information thus gained during the last three decades has not greatly advanced knowledge of the subject.

Although the aforementioned investigations were continued also during the following year, as shown by the results published in the 26th Annual Report (1905, p. 233–280), a new approach to the subject of soil bacteriology could then be definitely observed, namely an attempt to measure the fertility of the soil from determinations of nitrogen changes. Considerable attention was then being paid to the production of ammonia during the decomposition of proteins and other organic nitrogenous compounds in the soil. This new phase of bacteriology was gradually replacing the previous interest in the problem of nitrogen-fixation. A study was undertaken of the fertility of different soils, as measured by their crop yields, in cylinders and in field plots. The results thus obtained were compared with the ammonifying power of the same

soils, as measured by the formation of ammonia upon addition of nitrogenous organic compounds.

Just as the studies of the process of non-symbiotic nitrogen fixation followed directly the work of Winogradsky and Beijerinck on the same subject, investigations of ammonia-formation in the process of decomposition of organic matter in soil and the study of the rate of "ammonification" as an index of the productive capacity of the soil, followed directly the work of Remy. Löhnis in Germany and Lipman in this country may be considered as the first and most outstanding representatives of the "ammonification" studies carried out in Europe and in America, respectively. These two bacteriologists became the outstanding leaders in the investigation of several distinct soil microbiological processes; namely, ammonification, nitrification, nitrogen-fixation, and denitrification. The results obtained in these studies were believed to indicate that measurements of the biological condition of the soil could serve as a reliable guide to the productive capacity of the soil. The period of 1904–1905 can, therefore, be considered as one of interest, not only in the development of soil bacteriology at the New Jersey Station, but in the world as a whole.

The following year (27th Annual Report 1906, p. 119–188) was devoted practically entirely to ammonification studies. Soils of different origin as well as the same type of soil under different systems of fertilization were compared in ability to produce ammonia from various organic compounds. Ammonia formation by pure cultures of bacteria, especially *Bac. mycoides*, was also studied. Particular attention should be called here to one investigation carried out that year which may be considered as the direct forerunner of the now popular Azotobacter method for determining the presence and abundance of available minerals in soil. This method is based upon the ability of Azotobacter to grow in a solution containing an adequate supply of energy with the particular soil as the only source of one specific nutrient element. This method was later developed extensively by Christensen in Denmark and is at present applied on a large scale in Europe by Niklas and others, without sufficient credit being given, however, to its originator. The Annual Report for 1906 definitely states: "It would seem . . . . that nitrogen-fixing bacteria of the Azotobacter type, which are largely independent of the supply of combined nitrogen in the soil, could be made to grow in mannite or dextrose solutions devoid of any mineral nutrients, but provided with quantities of sterile soil. Theoretically, it would also appear that the development of the Azotobacter organisms, and the accompanying fixation of nitrogen, should be in proportion to the amount of mineral nutrients supplied by the sterile soil." The results obtained from a series of investigations showed that "everything being equal, bacterial growth will be determined by the rate of solution of the mineral nutrients, and particularly of the soil phosphates." Those soils which contained the largest amount of phosphates in an available form allowed the most vigorous development of the bacteria and, as a result of this, also of the amount of nitrogen fixed. "There was proportionately and absolutely more Azotobac-

ter growth in the mannite solution containing larger amounts of phosphates of greater initial solubility."

In 1907 P. E. Brown, a student at Rutgers, was appointed assistant chemist, and for several years, contributions from the Station to the subject of soil bacteriology were under the joint authorship of Lipman and Brown. The next paper (28th Annual Report, p. 141–204) contains a continuation of the investigations on the ammonifying capacity of the soil. An abnormal soil from Madison, Wisconsin, was studied in great detail; it was found that the unfavorable soil conditions could be corrected by treatment of the soil with carbon bisulfide; the improvement in the productive capacity of the soil was found to run parallel with an increase in the ammonifying, nitrifying, and nitrogen-fixing capacities and with a decrease in the denitrifying capacity of the soil. Further studies of the inoculation of soil with Azotobacter led, again, to definite conclusions that this alone did not bring about any increase in the nitrogen resources of the soil. The organism could not survive in soils which did not offer suitable conditions for its growth. An important contribution appeared in 1907, in the form of a joint paper with Doctor E. B. Voorhees and published as Bulletin 194 of the Office of Experiment Stations under the title "A Review of Investigations in Soil Bacteriology." This paper presented a detailed summary of the subject of the bacteriology of the soil and was at that time as complete a review of this subject as had ever been made available in the English language.

Various investigations dealing with ammonification, nitrification, and nitrogen-fixation in soil and in artificial culture media were continued during the following year (29th Annual Report, 1908, p. 95–147); however, new lines of attack of the soil microbiological complex were begun that year. Among the most important problems considered were the study of the influence of dextrose and other carbohydrates upon the biological activities in soil, as measured by ammonification of peptone, urea, and gelatin, as well as by bacterial multiplication; the utilization of the soil or tumbler method, as compared with the solution method, for the study of bacteriological activities in soil; and a comparative study of methods and culture media for measuring bacterial activities and bacterial numbers in soil. These investigations, although following in the course of logical development of the previous studies, marked important steps in the advance of the subject of soil bacteriology. A comparative study of different media for the determination of abundance of bacteria in soil resulted in the development of a synthetic agar medium which gave considerably larger numbers of bacteria than did the common bouillon agar previously employed; it was also standard in composition and, consequently, could be easily duplicated without affecting bacterial development. The same year witnessed the publication by Lipman of the now well-known book "Bacteria in Relation to Country Life" (MacMillan Co., New York, 1908). Although this book has never gone into a second edition, it was reprinted a number of times and was used extensively in colleges and in schools, as well as by farmers and county

agents; it has contributed materially to the dissemination of correct information concerning the rôle of bacteria in agriculture in general and in soil science in particular.

During the following two years (30th Annual Report, 1909, p. 117–222; 31st Annual Report, 1910, p. 89–182) the solution methods for the study of soil bacteriological processes were completely abandoned; their place was taken by the tumbler or soil methods, especially for the study of ammonification and nitrification. A detailed investigation of the influence of chemical, physical, and mechanical soil properties on the process of ammonification was also carried out. The relative availability of organic nitrogenous materials was determined by the rate of their transformation in the soil into ammonia and nitrate. It was demonstrated that in the decomposition of materials of plant origin containing only a small percentage of nitrogen the relatively abundant supply of carbohydrates leads to an extensive development of fungi and bacteria; these use up the nitrogen for the production of microbial cell substance. The carbon-nitrogen ratio of an organic material undergoing decomposition was found to be an important factor in influencing the rate of liberation of the nitrogen in an available form. The results of these investigations led to the suggestion that knowledge of the carbon-nitrogen ratio of organic matter is essential for an understanding of the availability of the nitrogen in the organic substances added to the soil.

The peak of investigations in soil bacteriology carried out directly by Doctor Lipman was reached in 1911. That year, his major assistant, P. E. Brown, left the station to assume an important position in the field of soil bacteriology at the Iowa Experiment Station, and several new members were added to the staff of the New Jersey Station; notably, A. W. Blair, who was to assist for many years to come in carrying out the field studies as well as the chemical investigations of the soil, and H. C. McLean, who was to devote his time largely to the soil bacteriological investigations. The Department of Soil Chemistry and Bacteriology (32nd Annual Report, 1911, p. 159–267) continued its investigations of the availability of nitrogenous materials in soil, as measured by the ammonification process, and of the influence of stable manure, nitrate of soda, and various stimulants on ammonification. Studies of the influence of protozoa and of soil pasteurization on ammonification continued for many years at the Station. An interesting attempt was made that year (*Bot. Gaz.* 51: 454–460, 1911) to systematize the terminology of soil bacteriological processes. A number of new terms to define certain established soil processes were suggested. Some of these, such as "azofication," "sulfofication," "ferrification," have since found a limited application in soil bacteriological literature; however, many others were proposed, which have never been used. Doctor Lipman published, during the same year, "A Laboratory Guide in Soil Bacteriology" (with P. E. Brown as joint author) and several chapters on "Soil Bacteria in Relation to Soil Fertility" in Marshall's *Microbiology*. Both of these proved useful for many years to students and investigators as sources of information concerning soil bacteria and their rôle in soil processes.

The decade from 1901 to 1911 resulted in a series of brilliant contributions by Doctor Lipman to our understanding of the rôle of bacteria in soil processes, especially in nitrogen-fixation and in decomposition of plant and animal residues added to the soil. His research activities, however, were not limited to the bacteria of the soil; these years were also marked by extensive field studies and by a growing interest in soil fertility problems.

## THE SECOND PERIOD, 1911–

The appointment of Doctor Lipman to the directorship of the New Jersey Station in 1911 prevented him from carrying out further the investigations on soil chemistry and bacteriology. He has continued, however, to supervise, guide, assist, and stimulate his associates and the large number of graduate students and assistants who have gathered around him to receive their training in the field of soil bacteriology. Many of the investigations carried out since 1911 were either initiated directly by Doctor Lipman or begun at his suggestion. It is sufficient to call attention to some of these problems.

*The occurrence of protozoa in soil and their rôle in soil processes.* The theory proposed (1909–1913) by Russell and Hutchinson at the Rothamsted Station that the protozoa of the soil keep bacterial development in check and that the favorable effect of partial sterilization upon soil fertility is due to the destruction of protozoa aroused considerable interest. Doctor Lipman and his associates undertook a series of systematic investigations on the occurrence of protozoa in soil and their relations to bacteria and to soil processes. The results obtained pointed to the great abundance of protozoa in soil; they tended to modify the earlier conception, however, that protozoa exert a controlling effect upon soil processes.

*The rôle of bacteria in the oxidation of sulfur and the transformation of insoluble phosphates into soluble forms.* It was found that as a result of composting sulfur, rock phosphate, and soil, the sulfur became oxidized to sulfuric acid and the latter interacted with the phosphate to render it soluble. This process was biological in nature, since when a fresh compost was inoculated with some material from an older compost, the processes began to take place much more rapidly. A detailed study of the organisms concerned in the process finally resulted in the isolation of a highly active sulfur-oxidizing bacterium, later named *Thiobacillus thiooxidans.*

*Continuation of field, cylinder, and pot experiments.* These consisted in such studies as the availability of different nitrogenous fertilizers, a comparison of organic and inorganic fertilizers, the influence of lime upon crop production, and factors influencing protein content of legumes.

In addition to these three major fields of investigation, a number of other problems in soil chemistry and bacteriology received more or less attention, such as the influence of bacteria supplied in the stable manure upon the decomposition of the organic matter added to soil, especially green manures; the influence of ferrous sulfate and gypsum on crop yield and nitrogen recovery;

the associative growth of legumes and non-legumes; the formation of carbon dioxide and nitrates in the presence of large amounts of carbohydrates. These studies led to several important new lines of attack of the chemical and bacteriological soil problems, begun by associates and students of Doctor Lipman under his direct and indirect supervision. The problem of oxidation of sulfur in soil resulted in detailed studies on the use of this process for the transformation of insoluble phosphates into soluble forms. These investigations were directly responsible for a more scientific use of sulfur in agriculture. Among the practical applications it is sufficient to mention: 1, the control of the soil reaction: a specific acid reaction suppressing the development of certain plant pathogens, notably the organism causing potato scab; 2, the control of the alkalinity in "black-alkali" soils. The investigations on the soil population led later to extensive studies of soil fungi, soil protozoa, and soil actinomyces and of their rôle in soil processes.

Doctor Lipman's contributions to soil science have had a marked effect upon the further development of this subject, particularly soil microbiology and soil chemistry, especially in this country. His contributions to our knowledge of the problem of *non-symbiotic nitrogen fixation* and of the *decomposition of organic matter with the liberation of nitrogen in an available form* can be considered the most original and important results in his investigations. If he had done nothing more, his place as an investigator in the field of soil science would be assured. Add to that his important contributions to our knowledge of the fertilizer requirements of plants and of the rôle of microörganisms in soil processes, and one will readily appreciate the value of his work in advancing the theoretical and applied phases of soil science.

Doctor Lipman's investigations came within a period of historical development of soil microbiology when both scientists and practical agriculturists were asking for applications of this science to agriculture. His work falls during a period of transition between the science developed in the laboratory and the application of the results thus obtained to field conditions. He contributed to both and thus helped to carry the science through one of the most difficult periods of its development. He has not only helped to advance the science of the soil, but also to digest and interpret it and to point to the applications of the science to practical agriculture. His contributions to agriculture in general and to soil science in particular are far from ended. This is evidenced by the fact that he is utilizing the sabbatical year granted to him by the Trustees of the College and Station, to complete a monumental work on the plant food resources of the United States.

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# JACOB G. LIPMAN AND NEW JERSEY AGRICULTURE

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While Doctor Lipman was still a student at Rutgers College, his determination to conquer difficult situations betokened his future contributions to New Jersey agriculture. He has told how, beginning in his freshman year, he would rise at 4 o'clock in the morning to assist with the milking of the College Farm herd. His college day over, he would return to the farm, which was more than a mile from the college campus, to do his share of the evening milking. It is this indomitable spirit that has brought to him national and international recognition in the field of agriculture, particularly in soil science. He was not afraid of hard work in his college days, and this habit of hard work has grown as the years have gone by.

He early realized that to be of value to agriculture in New Jersey, or anywhere else for that matter, he must thoroughly master all phases of the problem. He therefore set himself the task of gaining knowledge in all the sciences related to agriculture. He studied the geological origin of soil and its chemical, physical, and biological properties—how plants grow and get their nourishment; the care and feeding of animals; the marketing of crops; the economic problems which confront the farmer; and many other subjects.

He was fortunate, indeed, in having as his teacher and later as his chief Dr. E. B. Voorhees, who was professor of agriculture in Rutgers and director of the Agricultural Experiment Station. Although Doctor Lipman received guidance and inspiration from Doctor Voorhees, nevertheless, he showed determination to do his own work and to advance only as his record of work entitled him to advancement.

Just as Doctor Lipman began his work as assistant chemist in the Experiment Station, Doctor Voorhees was inaugurating his famous cylinder experiments for the study of nitrogen availability and nitrogen gains and losses in the soil. Doctor Lipman developed this work, and his results in this field are known throughout the world, wherever there are agricultural experiment stations. His keen intellect and his knowledge of foreign languages enabled him to find out quickly what had been done by other workers on any problem that he was studying.

Among his early experiments should be mentioned those on the improvement of the poor sandy soils in certain sections of southern New Jersey. By these experiments he definitely showed that through the use of legume green manures,

[1] Journal Series paper of the New Jersey Agricultural Experiment Station, department of soil chemistry and bacteriology.

supplemented with commercial fertilizers, these soils could be built up to a state where they would produce good crops of vegetables, fruits, and forage crops without the use of farm manure. His work on soil organisms and the part they play in the decomposition of organic matter and the improvement of soils was so outstanding that today thousands of farmers throughout New Jersey, and in other states and other lands as well, owe Doctor Lipman a debt of gratitude for this work. Soon there followed his book on "Bacteria in Relation to Country Life," which deals specifically with many of the problems of farm life, such as the care of dairy products, sanitation and sewage disposal, and the production of silage. His work as a Farmers' Institute lecturer under Franklin Dey in the early years of this century gave him an excellent opportunity to meet the farmers of the state; wherever he went he made friends. The fact that he was always in demand as a speaker, having far more calls than he could meet, gave striking evidence of his popularity with the farmers. Likewise as a teacher in the four-year courses and in the short courses at Rutgers he made many friends who gave him loyal support when they went back to the farm.

On the death of his predecessor in the summer of 1911, Doctor Lipman was made director of the Experiment Station. This gave him a wider field of usefulness and a greater opportunity to use his knowledge and experience in the interest of New Jersey farmers. Even before he was made director, he saw the need for a careful survey of the soils of the state. The Bureau of Soils of the U. S. Department of Agriculture had already surveyed, mapped, and published results on the Salem and Trenton areas. About 1910, through the coöperation of the Geological Survey of New Jersey, the Bureau of Soils of the U. S. Department of Agriculture, and the Experiment Station, Doctor Lipman was enabled to make a start on the survey of the Sussex area. A report of this survey was published in 1913. From the beginning of that work until all of the geological areas of the state had been surveyed and mapped, Doctor Lipman did not relinquish his purpose to compile a complete record of the soils of the state. Not only was the survey completed several years ago, but samples of soil representing practically every type in the state have been collected and analyzed, thus giving an inventory of the soil resources of the state.

Early in his administration as director, he saw the need for strengthening and enlarging the staff of workers and adding new departments. This, however, could not be done without increased appropriations, and increased appropriations could not be obtained without convincing legislators that such increases were necessary. Doctor Lipman's thorough knowledge of agricultural conditions in the state and his wide acquaintance with leading farmers and prominent business men enabled him to convince the members of the Legislature that there was a real need for greater support for agriculture in the state. Every year for the last 25 years he has gone before the Legislature with such convincing pleas that he has been able to enlarge the staff of workers

and add buildings and equipment to meet the increasing demands. A man of narrower views, with less knowledge of the problems which awaited solution and with less courage, would long ago have tired of going each year to a busy Legislature to convince its members that agriculture was sorely in need of help. But in this work, as has already been intimated, he had the loyal support of leading farmers, former students, service clubs, county organizations, and many others. But to Doctor Lipman an experiment station that can successfully meet the demands that are made upon it means more than buildings and equipment. He has realized that these material things are of little value without men of sound judgment, thoroughly trained for the work, and possessed with a spirit of real service.

His ability to forecast the trends of agricultural practice has enabled him at all times to be several steps ahead of actual requirements. Soon after his appointment as director, he visualized the possibility of a poultry industry in the state and proved his faith by appointing a poultry husbandman and establishing a department of poultry husbandry. The rapid development of this department and the steady growth of the industry in the state have fully justified his vision. In rapid succession came the departments of plant pathology, of agricultural extension, of vegetable gardening, of dairy husbandry as distinct from animal husbandry, of plant physiology, of agricultural engineering, of seed control, of water supplies and sewage disposal, of ornamental horticulture, and of agricultural economics.

Doctor Lipman's keen knowledge of human nature and his ability to choose the right man for the place and then give him a free hand and the needed equipment for his problem have been a strong factor in his success in advancing New Jersey agriculture. Rarely does one find an administrator who combines such sound organizing ability with a liberal attitude and high standards of achievement. He saw the general problem and then trusted the department head to work out the details, at the same time giving him encouragement and seeing that he had the necessary facilities for carrying on the work. Nor did he overlook the practical side of the problem. When a piece of research was completed he made it possible for the results to be taken to the farmer. This was accomplished through the Extension Service, through lectures by heads of departments, through news releases, farm papers, correspondence, and personal visits by members of the staff.

At times, during the past 25 years, there have been influences tending in the direction of making the Agricultural College a vocational or trade school. When such an issue has been raised, always Doctor Lipman has taken a firm stand in favor of a thorough training in the fundamental sciences. Very largely through his influence the standard has been kept high, and thus the Agricultural College has sent out men of sound training, to take their places on the farm, in research, as county agents, in industry, in agricultural journalism, and in many other fields.

During the War, Doctor Lipman, as director and dean of the Agricultural

College, had many difficult situations to face. A large number of the staff entered the Service, and commercial organizations were competing with the stations for men who had been carefully trained for specific work. Notwithstanding this, Doctor Lipman, with the staff that he was able to hold, so planned and directed the work that the station ably took its part in increasing crop production. In this way the value of its work first became known to many. This new challenge to service brought new responsibilities and a necessity for greater financial support. New demands for service from farmers' organizations scattered here and there over the state brought many new problems. Again Doctor Lipman's vision and foresight enabled him to forestall trouble by asking the coöperation of the leading state farmers' organizations in the planning of some of the important research projects. The State Potato Growers' Association, State Poultry Association, State Horticultural Society, and the American Cranberry Growers' Association each responded by appointing a committee to visit the station and consult with the staff members who were directly concerned with the work of these organizations.

Special appropriations granted in most instances at the request of interested groups, were made for new lines of research. Again credit must be given Doctor Lipman for anticipating a broader service for the station. In the years immediately following the World War, he realized that the rapid urban and suburban development in the state would bring to the station new problems, and was convinced that this new challenge must be met. Thus there was inaugurated research in water supplies and sewage disposal, in agricultural biochemistry, in farm economics, and in landscape gardening; short courses were established in turf management, cheese making, ice cream manufacturing, and ornamental horticulture.

An ancient writer[2] has said, "Where there is no vision, the people perish." Doctor Lipman is a man of vision and having had a vision of what things should be, he has done yeoman service to bring these things to pass. He has seen clearly the changes and developments that are taking place in the agriculture of the state and nation and has thrown his power and influence on the side of constructive improvement. He has consistently advocated the control of soil erosion; he has, in season and out, preached the gospel of soil improvement through the use of lime, fertilizer, and green manures; he has called attention to the necessity for better land utilization, by taking out of cultivation large areas of marginal land, by the creation of additional parks and playgrounds, and by forest conservation; he has ever been watchful of the farmer's interest when laws were being framed to control the manufacture and sale of commercial fertilizer, lime, feeding stuffs, and insecticides, and for the testing of seeds for purity and germination.

A few paragraphs taken from the History of the Experiment Station, published in 1932[3] would seem to form a fitting close for this tribute:

[2] *Proverbs* 29: 18.

[3] Woodward, C., and Waller, I. G. 1932 New Jersey's Agricultural Experiment Station, 1880–1930.

Throughout Dr. Lipman's administration we find the evolution of a philosophy of agriculture leadership—dynamic, but flexible in its relation to public needs....

In his annual report for 1923, Dr. Lipman discussed at length the marked trend toward specialization in New Jersey agriculture, pointing out the problems arising therefrom—insect and disease control, risk from crop failures, and poor markets. The Station, he said, should shape its program with due consideration for these conditions.

Subsequently we find Dr. Lipman constantly pointing to social and economic trends as a guide for future policy. Through the agricultural history of New Jersey like a red thread has run the evidence of economic pressure. Metropolitan expansion has meant changes in the types of agriculture, and city interests have penetrated into the country, introducing new economic and social influences....

Finally, Dr. Lipman has urged that the Station's service should be planned so as to fit best into a comprehensive scheme of state development. Research, he has claimed, must be organized not only to meet present day needs but to provide for far-reaching future adjustments in the agricultural industry.

Doctor Lipman himself has expressed his vision of the future services of the station in the following manner:[4]

As the agriculture of the state changes and as the needs of the state as a whole change, adjustments must be made for dealing with the problems as they arise....

As one looks ahead to the future of the institution he is made to realize both its opportunities and its responsibilities. Together with the College of Agriculture, it must further improve its resources as to land, buildings, and equipment. Cognizance must be taken of the growing demand of our industries for research facilities that only a well organized research institution can provide. With the coming years, our experiment stations will need to reckon more and more with conditions that govern the accepting of research grants from industries who are willing to pay for the research service but who, as a part of the economic life of the state, have a right to expect help analogous to that given to the agricultural industry. Beyond that, various organizations, like those of the livestock breeders, dairymen, gardeners, distributors of various commodities, manufacturers of implements, garden clubs and country clubs—will expect the institution to formulate policies, and to help toward their execution, for the sake of promoting the interests not alone of individuals, but of larger or smaller groups that have an interest in economic and social progress. The station, through its research and educational policy, should aim to make the state more attractive to its residents culturally as well as economically. If this assumption is correct, the institution will need to assume a larger responsibility in dealing with the esthetic and cultural needs of the state.

What more could a man wish to have said of him than that he devoted his whole life to making his State a better place to live in—better for the farmer, for the business and the professional man, for the laborer—for all the people?

[4] Woodward, C., and Waller, I. G. 1932 New Jersey's Agricultural Experiment Station, 1880–1930. (Quoted from *Ann. Rpt. N. J. Agr. Exp. Sta.* 1930: 9–10.)

# JACOB G. LIPMAN AS TEACHER AND DIRECTOR OF RESEARCH

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The essential progress of education and of science through the centuries has been centered around the personalities and teachings or the investigations and accomplishments of a comparatively few individuals who have lived and worked quietly and forcefully. In the development of the agricultural sciences through the modern period one of these gifted leaders, Dr. Jacob G. Lipman, plays the dual rôle of teacher and director of research.

In any effort to describe Doctor Lipman's ability in the one field or to evaluate his accomplishments in the other, one promptly finds how difficult it is to separate the two, since his method and influence, so dominantly inspirational, suffuse them both alike, and the teacher becomes at once a director, and the director, a teacher of the highest type.

Among the many personal attributes that contribute to the well-earned reputation and immediate success of Doctor Lipman as a teacher it is doubtful whether any are of more fundamental importance than the exceptional evenness and continuity of his temperament and patience. I am sure I speak for each and every one of his many students, past or present, when I say that on no occasion is he ever found too busy over other matters, whether in the classroom, laboratory, or office, to go into the finest details of a problem in an effort to develop the fullest possible understanding in the mind of the individual. Always there is that enduring willingness to go to the very end of the way in the discussion of any subject with the hope that there will result a thoroughly comprehensive line of thought or of action, whether it pertain to pure theory in the classroom or to a method of procedure in the laboratory.

Associated with this exceptional facility at all times is, of course, that inimitable sense of humor for which he more recently has become well known. This has assisted him not only in smoothing many a rough spot whether by way of lightening a point of discussion or in disarming argument or debate that promised to become unnecessarily heated. It doubtless has also meant much to him, personally, in bearing the heavy load of responsibility he always has carried with such an air of ease throughout these many years.

Although his unlimited tolerance and patience under the most trying circumstances have provided Doctor Lipman with outstanding advantages from the pedagogical standpoint, it is the sheer keenness and drive of his mind in the extemporaneous analysis of a problem, the vastness of the ready store of knowledge he always has at hand, and the thoroughly precise and orderly manner in which he has developed and maintained this mental encyclopaedia

that constitute the more technical background of his ability and finesse, both as a teacher and as a director of research. Little of the past that is important is ever forgotten; into the future is ever ranging a fine and powerful imagination; during the immediate present there is always that smooth joining of current ideas and experiences to those of the past, in preparation for the days to come, with an apperception of extraordinary clearness. It is his so capable handling of a preeminently able mind in this important field that has enabled him progressively to play the important rôle he has in the international development of scientific agriculture.

Without doubt the boyhood experience of Doctor Lipman on a well-developed Colony Farm in New Jersey under the inspiring instruction of an able teacher of agriculture awakened in him a deep love of growing things and a genuine appreciation of the unlimited possibilities of scientific agriculture. There is also little doubt that the winning of a scholarship at the Baron de Hirsch School which brought him in contact with Doctor Voorhees was a most important milestone in his career. The long period of diligent training in soil fertility, and particularly in soil bacteriology, that followed is a substantial manifestation of the strength of that early faith, constituting, as it did, the sound basis upon which he planned his professional career and developed his life work that has meant so much to soil science.

As a result of his appointment to the teaching staff of Rutgers and, subsequently, to the directorship of the Experiment Station and the deanship of the College of Agriculture he established the most intimate connection possible with both graduate and undergraduate students of agriculture in that institution. Thus did the boyhood dreams, worked out in part, at least, on a New Jersey farm, carry Doctor Lipman up from the fields to the classroom and on through the laboratory to leadership in a new and growing science and to a broad leadership among men.

The development of the New Jersey College of Agriculture with its Graduate School to the high place it now holds is a monument to Doctor Lipman's accomplishments in the field of agricultural education. There can be no question as to the highly important rôle this organization has played in the rural development of New Jersey. It has been through the undergraduate student body of the College of Agriculture that he has touched so many of the present and future agricultural leaders not only of New Jersey but of other states as well in a way that has meant so much to agricultural leadership, especially in rural communities. This has been the finest and most important of the several types of "extension" work for which that institution has been responsible.

As a teacher, Doctor Lipman also has exerted a strong human influence over rural life and culture through the contact he has developed and maintained with the "Short Course" students of agriculture who regularly come to the college for limited periods of instruction in the more rudimentary subjects of agriculture during the winter months. Here, indeed, he has found a direct

approach to the farm and an excellent opportunity to send forth the findings on the experimental plots or in the laboratory to trial under intensely practical conditions by a messenger who will himself eventually be the practitioner and who usually serves also as a demonstrator in his own community. The Short Course in New Jersey has been strongly developed and has come to represent an important instructional unit for those boys who feel they can not afford the time or money to take the regular four-year training. As an assistant to Doctor Lipman in his soil fertility course for these students during several winters, I could not but observe the remarkable opportunity he had thereby developed for a direct contact with those young farmers of the state.

It is also as a teacher, of agriculture, essentially, that Doctor Lipman has played such an important part in the development of New Jersey's remarkably fine extension system to serve what has come to be a highly specialized type of agriculture in most parts of the state. Although extension work in New Jersey began with the passage of the act in 1864 which designated the Rutgers Scientific School the Land Grant College for New Jersey, the elaborate form to which it is now developed is of comparatively recent origin, having followed, naturally, the expansion and elaboration of the experimental phases of the work. Thus, throughout the state, hundreds of farmer's meetings and conferences of one type or another have been organized to follow up those early lectures of Doctor Cook, and later of Doctor Voorhees, on a wide variety of agricultural subjects. At the more importanf of such public meetings Doctor Lipman has lectured scores of times in practically every part of the state. This phase of the work of the institution has been of the utmost importance in furthering agricultural development since, just as in the instance of the Short Course students, it is the most direct and satisfactory way of converting theory into practice. After all, it has been the applied phase of our research work that has made for the rapid development of American agriculture, even though we may now realize that this development has not always been judicious and sound from every standpoint at all times.

It was likewise as a teacher, in part at least, that Doctor Lipman, shortly after his advancement to the directorship of the Experiment Station, became interested in the development of the Graduate School in the College. Here, however, he also appears in the rôle of director of research, and it becomes more difficult in this, perhaps, than in any other field sharply to differentiate the two functions and to say where the responsibilities of the teacher and those of the director begin and end.

The Graduate School had a most interesting beginning, based largely on the lively interest of important commercial houses in establishing fellowships for the investigation of definite agricultural problems. This was at the time when the importance of agricultural research was coming to be felt very strongly and its control over the production of commodities destined for agricultural consumption was exerting itself rather sharply. Since those early years, 1907–1915, the names of Brown, Lint, Coleman, Koch, Cook, Kopeloff,

and others have impressed themselves on those who have followed, as real pioneers in the early organization of the work and of the school.

It is a further tribute to Doctor Lipman, both as a teacher and as a director, that the quality of the research work developed through those early periods and through its transition into the modern stage was always at par. At all times his students have been inspired by the knowledge that he was making every effort to provide their essential needs in the work. Not infrequently, too, much-needed conveniences have become available at the expense of his personal exchequer. One of the finest of such instances is his personal contribution to the endowment of the Cook-Voorhees Foundation in Soil Science in honor of the earlier directors of the Experiment Station who immediately preceded him. The earnings of the handsome fund that was developed in this cause are now used for the regular support of a research fellowship.

Although the early work of the Graduate School centered largely in soil fertility and closely allied subjects it broadened rapidly as the institution grew, until it now involves practically all the fields covered by the work of the College and of the Experiment Station. It would be invidious, indeed, to single out the work of particular departments for mention in a space so small as to preclude reference to the programs and progress of all. Suffice it to say that the researches and findings in many, if not all of them, have been distinctly basic to the science they represent and, as such, have attracted wide attention. Among them, the Department of Soil Chemistry and Bacteriology, always closest, of course, to the heart of Doctor Lipman, has doubtless led the way to the international recognition which the institution now enjoys.

In his rôle as teacher in the development of the Graduate School, Doctor Lipman's contacts became much wider than the confines of the state or even of the nation. As early as the mid-period of its development, 1915–1920, his name in the field of soil science had become internationally known, and students from many foreign countries began to find their way to Rutgers. This was largely through his numerous scientific writings and SOIL SCIENCE, which he established, as well as his frequent attendance upon, and important contributions to the success of, scientific meetings abroad. At the present time this institution can probably claim a more cosmopolitan alumni group than any other Graduate School of its size in the country. Included in the list of foreign countries from which students have come to New Brunswick to study under Doctor Lipman are: Australia, Austria, Belgium, Brazil, Canada, China, Cuba, Czechoslovakia, Denmark, England, Estonia, France, Germany, Greece, Holland, India, Japan, Palestine, Puerto Rico, Russia, Santo Domingo, South Africa, Sweden, and Switzerland. This group has included fellowship holders from the International Education Board, from the Scandanavian-American Foundation, and from numerous other organizations and has joined students from time to time with various expeditions as soil scientists or representatives of other branches of agricultural research from this organization. Thus the development of the Graduate School at Rutgers has been one of the

really important sources of recognition for Doctor Lipman in soil science and has been used by him, in turn, as an effective instrument in the part he has played in the development of that science.

As a director of research, naturally Doctor Lipman's most important work has been in the development of the Experiment Station. In order to appreciate fully the great task he inherited from his predecessors in the work, one must visualize, briefly at least, the development of New Jersey agriculture from Colonial times.

First of all there was, of course, the gradual decline of agricultural production through the post-revolutionary period due to exhausted soils and to the absence of much-needed information on proper fertilizers and cultural methods. This extended well past the beginning of the nineteenth century, when the situation was periodically depressed or relieved by such circumstances as the Embargo Act, the War of 1812, and depressions, all of which led up to the so-called "Industrial Revolution" following 1830 that marked the transfer of the manufacture of clothing and of implements from the household to the factory. By 1850 the factory movement was well under way, and "commercialized agriculture" came into being with its rapid development of specialized implements for various operations and the use of marl, chemical fertilizers, and clovers, which had become an established necessity based on fact.

Between 1850 and 1860 there was a continued rapid and irrepressible development in agriculture. This was capped by the high war prices of 1861–1864. The post-war depression marked a turning point in the development of New Jersey agriculture, however, due to the early appearance of western competition in general farm products against those available from the high-priced land near the rapidly developing metropolitan areas of the East. This was the point where the New Jersey farmers turned to specialities in the form of vegetables, fruits, meat, and poultry. The "Experimental Farm" or "College Farm" was established in 1864 following the passage of the Morrill Land Grant Act in 1862 and the designation of Rutgers as the State College for the Benefit of Agriculture and of Mechanic Arts in 1864. There followed a varied program at the farm, involving many practical and important studies that continued up to 1880, when the Agricultural Experiment Station was formally established.

In the early work of the station it was quickly observed by Doctor Cook that "questions of soil fertility were most important both in scope and in the usefulness of results. . . ." During this period were also inaugurated a great variety of crop trials that contributed greatly to the later program of expansion under Doctor Voorhees. In this latter period the program of research was greatly enlarged, and broad efforts were made at a systematic extension of the results to the farmers of the state just as rapidly as possible—the forerunner of the present, comprehensive Extension Service. So we find the Experiment Station at the time Doctor Lipman took charge of it in 1911 fully ready for the period of specialization and readjustment that rapidly followed both in the fields of research as pertaining to the individual workers

and to the departments of work and in the agricultural enterprise which that research was to serve.

Although chemistry in its relation to soil fertility and to the composition of feeds was the dominant branch of the work in the early period, even prior to the establishment of the Experiment Station when basic studies in plant requirements were under way at the "College Farm" [marl and other studies (1868); fertilizer trials with wheat (1869), with cabbage (1870), with corn (1872); etc.], this was destined to give way to the Department of Soil Chemistry and Bacteriology and itself become largely a control division in the organization entrusted with the important work of fertilizer and feed control analyses.

At the time Doctor Lipman became director, the work of the Experiment Station was centered largely around five divisions of investigation established during the years indicated: biology (1888); entomology (1888); botany (1889); horticulture (1895); and soil science (1898). With the sharp trend toward specialization and the demands imposed by the World War for ever higher agricultural production, the organization of new departments of work in the Experiment Station progressed rapidly under Doctor Lipman's leadership. Up to the present time, twelve new but closely harmonized sections have been added. These include: plant pathology (1911); poultry husbandry (1911); seed analysis (1912): dairy husbandry (1912); extension service (1912, though informally inaugurated 1864); agronomy (1914); agricultural economics (1917); plant physiology (1918); agricultural engineering (1918); agricultural biochemistry (1925); and water and sewage research (1927). There are, too, the important departments of publications and library, which have grown steadily into an important part of the organization as a whole.

Thus it has been the ever quick and full recognition of the changing trends in agricultural development and the rapid fashioning of the investigational program to fit its varying needs that have made the Experiment Station such an important factor in the establishment of this most essential of all industries upon a thoroughly sound basis throughout the East. Frequently, however, it has not followed changes in agriculture but rather, through its pioneering studies, has anticipated the definite needs of the future and so has contributed in a very definite way to the deliberate moulding of the agricultural destiny of the State of New Jersey and of the Nation.

Although Doctor Lipman's work as a scientist has been in the field of soil fertility and especially in that of soil microbiology, the breadth of his understanding and the range of his vision in the development of American agriculture, whether as a teacher or as a director of research, are best exemplified in the fine institutions in the founding of which he has played so prominent a part. Since the establishment and perpetuity of this work have been so close to his heart for so many years, perhaps in closing these remarks upon his career as a teacher and director, we can best say with Sir John Russell, "Our sincere wish is that it [the Experiment Station] may long continue its prosperous career and that it may be as successful in the future as in the past in maintaining a great reputation through the excellence of its work and the distinction of its staff."

MEMBERS OF THE DEPARTMENT OF SOIL CHEMISTRY AND BACTERIOLOGY OF THE NEW JERSEY AGRICULTURAL EXPERIMENT STATION, 1932

# EARLY FERTILIZER WORK IN THE UNITED STATES

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## EARLIEST INTEREST IN FERTILIZERS

Perhaps the earliest definitely experimental work on soil fertility is that done in 1760 by George Washington, who was deeply interested in the conservation and improvement of soils. In the absence of commercial fertilizers he made many experiments with manures, marl, gypsum, and a variety of green manures, including lucerne (alfalfa). He also experimented with the use of common salt, dividing the field into 8-foot treated and untreated strips.

J. A. Binns of Loudoun County, Virginia, also began experimenting with gypsum in 1784 and after 19 years of experimental work published his results in a book, "A Treatise on Practical Husbandry," in which he described tests with various cereals and forage crops. Another early record on the use of gypsum states that about 1770 Jacob Burge used it in a garden in Philadelphia, Pa., which was observed by Richard Peters, afterward president of the Philadelphia Agricultural Society. Peters then extended these experiments with commercial gypsum on his own farm, which was located in what is now Fairmount Park.

C. T. Jackson describes, in the 1844 Report of the Commissioner of Patents, a commercial fertilizer based on the analysis of Peruvian guano. In this he used such substances as phosphate of lime and soda, carbonate and muriate of ammonia, sulfate and nitrate of potash, nitrate of soda, sulfate of magnesia, oxides of iron and manganese, and organic ammoniates derived from peat. This appears to be the earliest attempt at the preparation of artificial fertilizer mixtures in America. It is especially interesting to note that he included sulfate of magnesia and also compounds of manganese; the inclusion of these substances in fertilizers today is considered a new and developing problem.

It would appear that the first Act in the interest of agriculture was passed by the Legislature of Maryland in 1847, establishing the office of agricultural chemist to analyze soils, marls, and vegetable and mineral deposits of practical utility to agriculture. Dr. James Higgins in his three annual reports as incumbent of that office reports on the analysis of soils and fertilizer materials, but whether he made any field experiments is doubtful. He reports some field experiments by coöperating farmers. In his third report (1853) he says:

> I am happy to inform your Honorable Body that all and more than all which can be accomplished by an experimental farm, at the public expense, I have made arrangements to accomplish, by the aid of several public spirited gentlemen of our state. . . . have each agreed to set aside a portion of their farms for a series of carefully conducted experiments with differ-

ent manures on different crops . . . . they will form the first and only experiments yet made in our state or elsewhere, where all the causes influencing the production of a crop will be estimated and the separate value assigned to each.

These early investigators were strongly influenced by Liebig, in Germany, and by Lawes and Gilbert, in England. Higgins pays his respects to the former as follows:

Baron Liebig—a master genius—one of those great, vast and comprehensive minds, whose ideas become facts for mankind—reviewing the experience of those who had preceded him, and exploring with indomitable energy and skill the composition of the earth—giving to each tree, plant and shrub a tongue to utter words of eternal truth—to disclose their composition, and to show their necessities, has explained the laws for the production of vegetable life, in a simple and plain, yet thorough and irrefutable manner.

After discussing some of the results of Lawes and Gilbert he writes these words of appreciation:

The whole agricultural community, both in this country, as well as in England, are under deep obligations to these gentlemen, who, through a long series of years, conducted such careful and accurate experiments. These papers, and others which have preceded it, have given me and the people of our State much valuable information. I hope this will be some slight reward for their laborious experiments.

### ESTABLISHMENT OF FIELD TESTS AND CONTROL LAWS

In 1856 the Maryland Legislature passed an Act to establish an agricultural college, and in 1858 field experiments to test the relative values of the different manures (fertilizers) offered for sale in Baltimore and Washington were commenced on the college farm but were interrupted by financial distress and political unrest in state and nation.

Levi Stockbridge, of Massachusetts, in 1867 began experiments with commercial fertilizers on the college farm and inaugurated pot experiments with the thought that the nutritional needs of the plant are determined by the chemical composition of the plant. He extended this experimentation to large boxes in 1871 and in 1875 concluded that the only substances the farmer must supply were nitrogen, potash, and phosphoric acid, and that there was a relation between crop and quantity of fertilizer applied, if these elements were supplied in the proportion found in the *entire* plant. He devised fertilizer formulas for many crops and in 1878 contributed the royalties derived therefrom for the establishment of an experiment station, which in 1882 became the Massachusetts Agricultural Experiment Station by Act of the State Legislature. F. H. Storer, dean of the Bussey Institution, Massachusetts, in 1871 inaugurated field tests of fertilizers on the farm of the Bussey Institution and made analyses of commercial fertilizers.

The report by C. A. Goessmann on commercial fertilizer analyses in 1873 led to the enactment of the Massachusetts Fertilizer Control Act of May 26, 1873, the first law in the United States providing for an official inspection of fertilizers. He was among the first to study the effect of different fertilizers on

the composition of fruits and showed that the relative proportions of the fertilizer elements affected the quality of the fruits.

In 1853 William Johnson, at Yale Scientific School, Connecticut, published an article on superphosphate of lime in the *Country Gentleman* of February 1853, discussing the value of commercial fertilizers. In the same journal a year later, writing from Munich, Germany, in discussing the Moeckern Agricultural Experiment Station, he extolls "the great utility of such establishments and the hope that the organization of similar ones in the United States may be encouraged." On his return in 1855 he resumed his work of analysis and valuation of fertilizers and continued to agitate the question of fertilizer control. His work in keeping inferior or worthless fertilizers off the market in Connecticut, aroused public interest throughout the next two decades and resulted in the establishment of a State Experiment Station at Middletown, Connecticut, by Act of Legislature, with W. O. Atwater as director. Analysis of fertilizers was inaugurated, and farmers were urged to submit samples. In 1876, probably the first joint meeting of farmers and fertilizer manufacturers and dealers in the United States was held under the auspices of the station. This meeting recommended that all fertilizers sold in the state should be sold under a guarantee of composition to be determined by the station. Box and field experiments were conducted with W. H. Jordan as associate. In 1877 the station was removed to New Haven with Samuel W. Johnson as director. This important agricultural research and the valuation of commercial fertilizers on a scientific basis was pioneer work, and its influence extended widely throughout the United States.

In 1855 McAllister, near the general site of what is now the Pennsylvania Experiment Station Farm, supervised the laying out of experimental tracts on the school farm and planned experiments in the rotation of crops and the application and use of fertilizers. This Farmers' High School became in 1862 the Agricultural College of Pennsylvania, and in the first ten years of its existence its efforts were confined to simple experiments with fertilizers and methods of culture.

The first lysimeter work in America appears to be that done between 1867 and 1875 by E. L. Sturtevant, who later became the first director of the newly established New York Experiment Station. This lysimeter work was done on a farm owned jointly by him and his brothers near South Framingham, Massachusetts, known widely as Waushakum Farm, and was used in connection with studies on the percolation of water in soils and drainage experiments.

Although Maine, in 1868, began some simple fertilizer experiments, it was not until 1880 that an experiment testing the different forms of phosphoric acid was started; this was later extended to include various fertilizer combinations.

While manager of the college farm in Ohio, Charles E. Thorne, under the early direction of Prof. N. S. Townshend, started some fertilizer and culture

experiments with several crops during the period of 1877 to 1881. In Tennessee some early work with fertilizers on wheat and pasture was started by by J. M. McBryde. The results of some fertilizer work on cotton done by the college on a tract of land in northern Alabama were published in 1875; and later fertilizer work was done at the college farm with cotton, corn, and potatoes. In Wisconsin, there were some early experiments between 1875 and 1880 by W. W. Daniells with fertilizer on corn. In Louisiana, W. C. Stubbs conducted some early experiments with fertilizers on sugar cane, oats, and corn at the Sugar Experiment Station established in 1885, and later with cotton, oats, and potatoes, at the State Experiment Station.

On the Experimental Farm of Illinois Industrial University, W. C. Flagg started some fertilizer experiments in 1871, and in 1872 Kansas began some experiments with fertilizer; Cornell University Experiment Station published in 1880 its first report on fertilizer experiments begun in 1878; in Kentucky, M. A. Scovell reported in 1885 on a fertilizer experiment with tobacco and later with other field crops; in Indiana, from 1879 to 1882 there were some fertilizer experiments with wheat, corn, oats, and grass, reported by C. L. Ingersoll; in Mississippi, F. A. Gulley conducted some fertilizer experiments with cotton and corn during the period 1880 to 1888; in Missouri, J. W. Sanborn reported fertilizer experiments on corn and wheat during the period 1883 to 1888; and in New Hampshire, G. H. Whitcher, conducted experiments with fertilizers before 1888.

At Pennsylvania State College, W. H. Jordan conducted, from 1881 to 1885, some general fertilizer experiments with dissolved bone black, ground bone, nitrate of soda, dried blood, sulfate of ammonia, muriate of potash, lime, ground limestone, plaster, and yard manure; experiments to show the effects of different forms of phosphoric acid on crops in rotation; and experiments with wheat using different amounts of commercial fertilizer.

Through the influence of G. H. Cook, professor of chemistry at Rutgers College, New Jersey, field experiments with fertilizers were begun in 1865. It was not until 1874, however, that an Act for the control of fertilizers was passed and control work undertaken by the institution. The New Jersey Agricultural Experiment Station was not established until 1880, when it took over the control and experimental functions of the college, with Professor Cook as director. The station followed the lead of Johnson at the Connecticut Agricultural Experiment Station in its conduct of fertilizer control work. Field Experiments with fertilizers were carried on at the college farm and also coöperatively with farmers in various parts of the state with different crops, and with analyses of these to determine the amounts of plant foods removed per acre. This early attempt at obtaining an inventory of fertility factors has in later years been extended by the present director, Dr. J. G. Lipman, in an excellent manner to the national domain.

The North Carolina Agricultural Experiment Station was established in 1877 and was authorized to analyze fertilizers, suppress fraud in the sale of com-

mercial fertilizers, and carry on experiments on the nutrition and growth of plants. Its right to publish analyses was challenged, and the question of the constitutionality of the fertilizer law was taken to the State Supreme Court, which decided in favor of the Department of Agriculture, thus settling an important question in fertilizer control administration in other states.

These early stations in Connecticut, Massachusetts, New Jersey, and North Carolina began the inspection of fertilizers. This work was strongly supported by the farmers and served an excellent purpose in improving the quality of fertilizers, and, by restraining the fraudulent, the control movement was of great help to the more honestly inclined fertilizer producers. The enactment of laws for fertilizer control soon spread into about 20 states east of the Mississippi River, where, under the influence of the Association of Official Agricultural Chemists, control became thoroughly organized. Although this association was formally organized in 1884, it was the outgrowth of an older Association of Agricultural Chemists formed in 1880, meeting first in Washington, later in Boston, Cincinnati, and Atlanta, and counting among its members such distinguished agricultural chemists as Goessmann, Johnson, Wiley, Jenkins, Caldwell, and Atwater. With the merging of this earlier association into the Association of Official Agricultural Chemists, S. W. Johnson became its first president, and H. W. Wiley, its second president in 1886. The latter as founder and secretary-treasurer from 1890 to 1912 became its militant leader for honesty and purity in foods, feeding stuffs, and fertilizers, with guaranteed analysis for the latter and chemical control by state chemists.

### EXPERIMENTAL WORK SUBSEQUENT TO THE HATCH ACT

After the passage of the Hatch Act in 1887 the scientific work of the experiment stations was greatly extended, and fertilizer work shared in this general improvement. Such fertilizer experimentation was rather largely confined to the older states east of the Mississippi River. The following will illustrate in a general way the character and scope of this period of fertilizer investigation by some of the state stations:

The Connecticut Station conducted studies on the effect of fertilizers on the chemical composition of corn, and various nitrogen sources were studied as to availability on different soils; the Massachusetts Station studied the effects of special fertilizers on fruits, vegetables, and field crops, investigated the effect of different plant food combinations on quantity and quality of tobacco grown in the Connecticut River Valley, and experimented on the relative value of different phosphates and potash carriers; the New Jersey Station made cylinder experiments on the relative availability of nitrogenous fertilizers and barnyard manure and conducted field experiments with various fertilizer materials and combinations; the Ohio Station made a long continued investigation relating to the maintenance of soil fertility which comprised experiments with fertilizers and manures on hundreds of tenth-acre plots on various

soil types of the state; the Illinois Station continued its field work on the management of soils in many regions of the state and made pot experiments with the different soil types of the state; the Kentucky Station by field experiments showed that the depleted bluegrass soils of the state were deficient in potash and conducted fertilizer experiments with tobacco, hemp, and corn, studying the effect of fertilizers on shrinkage and on the ratio of cob to kernel; West Virginia made 5-year comparisons of commercial fertilizers with barnyard manure in pasture studies; Mississippi studied the effect of fertilizers on cotton on a variety of soil types of the state; Louisiana similarly studied the effect on sugar cane over a long period of years; the Alabama Station determined the fertilizer needs of its important soil regions and particularly studied green manuring; North Carolina studied the use of tobacco by-products, the effect of commercial fertilizers on the various important soil types of the state, and the effect of different fertilization on nitrification in the soils and the availability of phosphates as affected by fineness; South Carolina studied the ratios of nitrogen, phosphoric acid, and potash for best cotton and other crop production and studied different methods of fertilizer placement to obtain maximum results.

### LONG TERM FERTILIZER EXPERIMENTS

Special mention should perhaps be made here to our long term experiments in the United States, which were inaugurated in these earlier periods of fertilizer experimentation at the Illinois, Pennsylvania, and Ohio Experiment Stations.

The Morrow plots at the Illinois Experiment Station, begun in 1879 by George E. Morrow, are the oldest soil experimental plots in America. The series originally contained seven plots, on part of which use was made of fertilizers and manure. Three of the original plots still remain, the others have been used for building purposes in the development of the University of Illinois. Subsequently other experimental plot work was begun in 1902 on the North Farm and in 1903 on the South Farm of the Experiment Station, by Cyril G. Hopkins, which are still under observation.

The oldest most extensive plot tests of fertilizers are those by the Pennsylvania Agricultural Experiment Station laid out in 1881 by W. H. Jordan. Four tiers of 36 plots, each one-eighth acre, are used for the growing of corn, oats, wheat, and mixed clover and timothy in rotation on Hagerstown clay loam, a prominent soil of the region. The objects were to test the comparative effects of the following treatments on the crops grown: single fertilizer ingredients; combinations of two ingredients; complete fertilizers; nitrogen in different forms and amounts; superphosphate and ground bone; manure in different amounts in comparison with commercial fertilizers; burnt lime and ground limestone used alone, and burnt lime used with manure; and land plaster. Jordan applied nitrogen, phosphoric acid, and potash at the rates of 24, 48, and 100 pounds, respectively, per acre as the standard treatment every second year, and on the corn and wheat crop different rates of nitrogen; namely, 24, 48, and 72 pounds per acre were applied in alternate years, using three different forms of nitrogen—dried blood, sodium nitrate, and ammonium sulfate.

The investigational plot work on fertilizers was begun at the Ohio Agricultural Experiment Station in 1893 by Charles E. Thorne, growing corn, oats, wheat, clover, and timothy in rotation, with applications of nitrogen, phosphoric acid, and potash, singly and in combination. With these tests at Wooster and at a number of other points in the state, Ohio has probably the most extensive outlay of plots in the United States.

In this connection the long term cylinder experiments of the New Jersey Experiment Station begun in 1898 and continued to this day by Dr. J. G. Lipman and Prof. A. W. Blair should also be mentioned. Corn, oats, wheat, and timothy were grown in rotation in 60 cylinders, each 4 feet deep and 23½ inches in diameter, open at both ends and set into the soil to simulate natural drainage as much as possible. Since the availability of nitrogen from different sources was the main object of the experiments, manures, dried blood, sodium nitrate, and ammonium sulfate were used in various combinations.

After the passage of the Adams Act in 1906, granting government support to research at the state experiment stations, another period of development in soil science began. There were studies of the fertilizer requirements of the principal soil types in different states; of the composition of certain plants as indicative of these requirements; of the effects of fertilizers on quality of crops; of the rôle of fertilizer constituents in plant nutrition; of the functions of lime; of the so-called deficiency diseases; and of many other lines of fertilizer research, thus bringing us up to the more recent developments which, however, lie outside of the scope of this brief summary of the earlier work in fertilizer experimentation in the United States. There remains to sketch even more briefly the development of the early fertilizer industry in the United States.

## EARLY DEVELOPMENT OF THE FERTILIZER INDUSTRY

The use, production, and sale of commercial fertilizer seem to have had their origin in Maryland. According to the Report on Agriculture of the U. S. Commissioner of Patents, 1854, guano was first used about 1824, when the editor of *The American Farmer* received two barrels of guano at Baltimore and distributed it for experimental purposes. P. T. Tyson in his first report as state agricultural chemist for Maryland, published in 1860, states that, "Maryland was the pioneer State in the use of guano in this country. According to my recollection, the first trial of it in the State was by Capt. A. S. Dungan, of a few bags brought by him from Peru, and applied to part of his corn crop. This I think was about the year 1832, and soon after the importation of it by the cargo was commenced." Baltimore City was the first and for a long time the only port for the importation of guanos from Peru, the Caribbean Sea, and the Gulf of Mexico. Some twenty barrels were shipped here from England, in 1840, but the first direct shipment from the Chincha Islands of Peru was received in 1841. For some time the guanos were used in their crude state, but soon became "manipulated." Guano reached its maximum importation into the United States in 1856, when it amounted to 50,000 tons. This entire

amount passed through the Baltimore market, and at that time no fertilizers were sold west of Pennsylvania. Likewise, Tyson in 1860 states, "The first bones used for manure in this country, it is believed, were crushed at the establishment of Mr. Wm. Trego, and sold to farmers in Harford and Montgomery counties in the year 1836."

In the third report by James Higgins, first agricultural chemist of the State of Maryland, published in 1853, there are enumerated and classified a considerable number of fertilizer materials then occurring in commerce, among them, guano, poudrette, bonedust, pure lime, magnesium lime, mineral phosphate of lime, wood ashes, potash, nitrate of potash, nitrate of soda, gypsum, shell marl, and green sand marl (Jersey marl). These appear to have been in use in 1853, but the specific dates of introduction of some of them are not so clear. In 1860, P. T. Tyson, second agricultural chemist for Maryland, devotes a chapter in his report to "Artificial Manures of Fertilizers," discussing the uncertain composition and money value of many of these, and giving suggestions "for protecting our farmers from frauds in fertilizers and adulterated guanos and other manures." The "brand" idea was already well developed, for he mentions such names as "Mapes' Super-phosphate," "Mapes' Nitrogenized," "DeBurg's Super-phosphate," "Coe's Super-phosphate," and others. Dr. R. W. L. Rasin—descended from an old Maryland family, and engaged with the Philadelphia Guano Company when it was organized in 1854 to work the guano producing islands near the coast of Venezuela, remaining with them until these were exhausted—states that in 1850, Chappell and Davison of Baltimore made some fertilizer in a small way at the same time that Mapes was experimenting. DeBurg made use of spent bone black from the sugar refineries, calling his product "dissolved bone black." Manufacture on a commercial scale was begun about 1853 by Mapes and by Rhodes, both in Baltimore. In 1855 Kettlewell, claiming to produce a more suitable agricultural product, produced his so-called "Kettlewell's manipulated guano," which appears to have been a mixture of highly nitrogenous Peruvian guano with highly phosphatic Mexican guano.

C. T. Jackson, of Boston, Mass., writes in the 1854 Report of the Commissioner of Patents (Agriculture) that a company had been formed in Rhode Island "for the manufacture of fish manure, and the fat menhaden of Providence river and Long Island sound will be used to produce both oil and fish-cake, and the latter being duly prepared so as to render it inodorous, will be sent into the agricultural market as an artificial guano." He also refers to acidulating the fish-cake. Although fish has been used since earliest times, even by our American Indians, this appears to be the first commercial manufacture of fish guano.

Sir John Lawes about 1842 invented the process of making superphosphate from natural rock phosphate with sulfuric acid in England, following the same idea suggested by Liebig for the sulfuric acid treatment of bone in 1840. This process soon came to be used in the United States. Baltimore became the first

center for the production of chemical fertilizers in the United States about 1850; this commercial production later extended to Richmond, Va., and Charleston, S. C. The quantity produced and sold was at first small, but in the next six years the use increased to 20,000 tons in the United States. The number of manufacturers was small, but by 1860 the census reports as many as 47 firms engaged in the manufacture of artificial or commercial fertilizers. With the development of the South Carolina phosphate beds in 1868 the industry was given a new impetus. Charleston soon became an important superphosphate manufacturing center, seven companies being engaged in the industry in South Carolina in 1870. The even more extensive deposits in Florida were not yet discovered and were not a commercial factor until 1888. The Tennessee deposits did not become commercially important until after 1892.

The industry grew rapidly from its small beginnings in 1850 to about 20,000 tons in 1856, and census figures show that by 1869 the production of fertilizers in the United States was about 153,000 tons, by 1889 about 1,900,000 tons, by 1909 about 5,600,000 tons, and by 1927 about 8,000,000 tons. From the pioneer days of the fertilizer industry a remarkable evolution in fertilizer manufacture has taken place, and the industry is now primarily a chemical one, dependent to a considerable extent on relatively pure chemical compounds.

# THE BEGINNINGS AND DEVELOPMENT OF SOIL MICROBIOLOGY IN THE UNITED STATES[1]

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Soil microbiology, or "soil bacteriology," as it was known for many years and is still called in some quarters, probably largely for sentimental reasons, is one of that great progeny of modern sciences developed during the latter part of the nineteenth century, the so-called "Golden Age of Science," from that prolific mother of so many sciences—Agriculture. It appeared along with Bacteriology, itself a child of Botany, one of the newer biological-agricultural sciences. And it also grew up along with soil science or pedology, another of the newer agricultural sciences, which developed largely from agricultural chemistry and geology. From these two closely related fields it derived its early name—"soil bacteriology"—and from both it drew techniques and viewpoints. But it also borrowed methods and theories from chemistry, physics, and other older sciences. In fact, as a science, soil bacteriology overlaps so many other fields that there has been some confusion as to its proper place in the whole scheme of science. But in this characteristic, it should be emphasized that it is no different from most of the modern so-called "applied sciences." And the complex relationships of the science should raise no question of its status as a distinct branch of knowledge. By all the criteria which are generally agreed upon as adequate, soil microbiology is certainly approaching maturity as a science, if, indeed, it is not quite full-grown now.

Although many suggestions appear in the writings of the early agricultural investigators, indicating the significance of "germs" in relation to crop production, it was not until the eighties of the last century that actual evidence of the occurrence and action of microörganisms in the soil was obtained. Boussingault in 1858 asserted that the soil contained germs, Pasteur in 1862 claimed that nitrification was a process brought about by a living ferment, Schönbein in 1868 stated that nitrates may be reduced to nitrites by fungi, and Schloesing and Müntz in 1877 proved Pasteur's contention, but it was not until Koch in 1881 developed the gelatine plate method for the isolation of pure cultures that bacteriological studies really began and attempts were made to investigate the microörganisms in the soil.

During the two decades following Koch's epoch-making contributions, many scientists were attracted to this new and important field, and considerable research was conducted to determine the character and significance of the

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activities of microörganisms in the soil under varying conditions. Probably no other science developed quite so rapidly, but, be that as it may, the growth of soil microbiology during this period was amazing, and great strides had been made toward its maturity as a science, when investigations began in this country.

Already Hellriegel and Wilfarth had conducted their classical experiments on the fixation of nitrogen by inoculated legumes and effectively settled the controversy which had been raging for many years over the question of the nitrogen nutrition of plants. Already Frank had described the causative organism and named it, and Beijerinck had also isolated the bacteria and given them a different name, thus creating a difficulty in nomenclature which persisted for many years and was not entirely settled even by the official action of the Society of American Bacteriologists. Already Winogradsky had succeeded in isolating the nitrifying bacteria and shown something of the nature of the process of nitrification, accomplishing what many others had attempted but failed to perform because of difficulties in technique. Already this same investigator had isolated and described a free-living anaerobic nitrogen-fixer, *Clostridium pasteurianum*; Berthelot had reported on the gains in nitrogen in fallow soils, presumably due to microörganisms, and a commercial culture, "Alinit," had appeared on the market for use in inoculating soils with nitrogen-fixing bacteria. Already Marchal had demonstrated the production of ammonia by many species of soil bacteria, and Omelianskii had shown the importance of bacteria in decomposing cellulose and had isolated two anaerobes functioning in the process. Already Gayon and Dupetit had isolated two organisms capable of reducing nitrates, Beijerinck had found an organism which reduced sulfates, and Winogradsky had studied the sulfur-oxidizing bacteria. And throughout the period many were studying the numbers of microörganisms in the soil and discussing their importance from the standpoint of soil fertility or productivity.

As it is difficult to fix definitely the time of the beginning of the science of soil microbiology, so is it quite impossible to give an actual date for the beginnings of the science in this country. Certain suggestions and comments regarding the bacteria in soils and especially regarding the growth and value of inoculated legumes appear in some of the earliest publications of the agricultural experiment stations. Indeed, some actual tests of the fixation of nitrogen by inoculated legumes had been made, notably those of Atwater, confirming Hellriegel and Wilfarth's work, but practically nothing else in the way of real scientific studies of soil microörganisms had been reported until just about the beginning of this century.

The work of Jacob G. Lipman, begun as a graduate student at Cornell University and continued at New Jersey, where he formed the first department of soil chemistry and bacteriology in the country, the investigations of Frederick D. Chester in Delaware, the studies on the legume bacteria and inoculation under George T. Moore at the Bureau of Plant Industry, and the work of

F. L. Stevens and W. A. Withers in North Carolina marked the actual beginning of soil microbiological research in this country. The publications of these investigators and of those of a few others which appeared in the very first years of the century stimulated and largely guided the extensive studies on soil microbiology which were conducted in the United States during the first two decades following 1900.

The problem of the nitrogen nutrition of plants had engaged the attention of the early agricultural chemists and was the subject of extended and often bitter controversy for many years. The mineral theory of plant feeding developed by Liebig in 1840 and the inescapable conclusion from the early experiments that plants could not use the nitrogen of the atmosphere but must have a supply of mineral nitrogen in the soil, led naturally to the development of the theory and practice of fertilization of the land with mineral fertilizers. In spite of the discovery of the ability of legumes, when well-inoculated, to draw upon the free nitrogen of the air, the problem of nitrogen fertilization was the subject of serious attention, and Liebig himself predicted that nothing would more certainly consummate the ruin of England than the scarcity of fertilizers, which would lead to a lack of food. It seemed evident to many that the exhaustion of the nitrate of soda deposits in Chile would mark the end of artificial nitrogen fertilizers and this would inevitably mean the end of the world. Indeed in 1898 Sir William Crookes in an address before the British Association for the Advancement of Science predicted that a scarcity of wheat would occur after 1931 and England, along with all other bread-eating nations, would be faced with famine unless the inexhaustible supply of nitrogen in the atmosphere could be transformed to nitrate fertilizer by electricity, to supplement the inadequate nitrate of soda deposits and maintain the nitrogen in the soil. He concluded that this was quite possible.

It was natural, in view of the general apprehension of a nitrogen shortage for food production, and also because of the interest in the problem of the nitrogen nutrition of plants, that the attention of the early soil bacteriologists should be more or less centered upon the relationship of microörganisms to nitrogen. Thus the great majority of the early studies involved the so-called "nitrogen" bacteria. The organisms that bring about the inoculation of legumes and enable them to utilize the free nitrogen of the atmosphere and the whole problem of legume growth and inoculation quite naturally were studied extensively both in the United States and abroad at the turn of the century, and the other nitrogen changes brought about by microörganisms, notably ammonification, nitrification, and nitrogen fixation, received almost as much attention, or perhaps even more, from the soil bacteriologists. The practical goal of much of the work was the solution of the problem of supplying nitrogen for future crops or the utilization of atmospheric nitrogen to build up and maintain the supply in the soil.

The work on the legume bacteria and on inoculation was concentrated mainly upon the development of pure cultures which would insure thorough

inoculation of legumes in the field and hence provide for a fixation of atmospheric nitrogen. Since the pure culture, Nitragin, put on the market in Germany by Nobbe had not given very satisfactory results, Moore and his associates attempted to develop new methods of culture that would give better inoculation, for it seemed obvious that inoculation with soil could hardly be depended upon and the various difficulties incident to its use overcome. The cotton culture method was devised and extensively tested around the country but unfortunately it was not so successful as had been hoped, and Chester showed that the difficulty with it was due to the inability of the organisms to withstand the drying on the cotton. Since reports from various stations bore out this conclusion, attempts were made to develop other types of cultures. It is undoubtedly true that much of the early pure culture inoculation failed because the cultures contained weak, inefficient bacteria or the wrong kind of organisms or perhaps only dead cells when the cultures were finally used. But in many cases the difficulties in the field tests by farmers were certainly attributable to the fact that other precautions in preparing the soil for the legume growth, such as liming, had not been observed. Even where everything possible was done, however, the cultures still, all too often, gave no benefits.

So the study of the legume bacteria has continued, and although the production of cultures has been developed on a commercial scale in recent years and successful inoculation generally follows their use, there are still some failures and difficulties in connection with inoculation. Some agricultural experiment stations still produce cultures which are distributed to farmers, apparently considering that they can produce better cultures than the commercial companies. But most of the investigators now are content to delegate culture production to commercial interests and devote their attention to the organisms themselves, realizing that further improvements in cultures must come from additional research on the bacteria and their characteristics.

The studies on Rhizobium in this country have been extensive, and much progress has been made in answering the questions of its morphology, its physiology, its cultural characters, its cross-inoculation relations, its inoculating power or efficiency, and its nitrogen-fixing power, and we are now approaching a solution of the problem of the mechanism of nitrogen fixation. At least six distinct species are now recognized, and characteristic physiological and cultural reactions are available for their differentiation. Certain definite cross-inoculation groups are distinguished, and the inoculating efficiency of various strains is recognized as important. The occurrence of a life cycle of the organisms has been demonstrated and a relationship to inoculation shown.

The actual amount of nitrogen fixed by well-inoculated legumes is still a matter of conjecture, however, in any individual case and probably varies widely depending upon all the conditions of the test. It is even believed that in certain cases inoculated legumes may fix no nitrogen at all. This, however, still remains to be proved. The fixation of nitrogen by the organisms when

grown alone, although studied in many experiments, is still an open question. The longevity of the various species in the soil has not yet been determined and probably never will be, for undoubtedly the conditions in the soil play a vital part in such a determination. Recent studies have indicated this fact. Sporadic attempts in the past to determine the occurrence of the organisms in the soil have been only partially successful, but recently a technique has appeared which merits further study and may serve as a means of determining the need for inoculation.

Further work on the physiology of the bacteria is necessary especially in connection with the differentiation of strains in order to provide a better knowledge of inoculation. Research to check on the life cycle of the organisms and on the relationship of the various stages of growth to inoculation is needed. Additional investigations are very desirable to determine the character and occurrence of fixation of nitrogen under known conditions. In short, although enormous progress has been made in the study of the symbiotic nitrogen fixation process since 1900, there is still much to be done and more complete and far-reaching investigations are sorely needed.

The non-symbiotic nitrogen fixation process was the subject of the early work of J. G. Lipman at New Jersey. Following the claims of Berthelot and the isolation of *Clostridium pasteurianum* by Winogradsky, Beijerinck in 1901 isolated and described two aerobic non-symbiotic nitrogen fixers and called them *Azotobacter chroococcum* and *Az. agile*. Lipman in 1903 isolated three additional species, *Az. vinelandii*, *Az. beijerinckii*, and *Az. woodstownii*. He also studied the conditions under which these organisms develop and pointed the way toward a more definite knowledge of their occurrence and action in the field. Much work has been done on this important group of organisms, a few additional species have been added and attempts have been made to inoculate soils in the field with pure cultures and thus bring about a fixation of nitrogen. These latter tests have all failed, and the commercial exploitation of cultures of supposed nitrogen fixers has involved some police work in certain states to protect farmers from unscrupulous salesmen of these spurious products. It is certain that some day there will be a method developed for inoculating soils with Azotobacter, but much work is necessary before this can be done. Much progress is being made in the study of the physiology and cultural characteristics of the organisms and the determination of their nitrogen-fixing power or efficiency. The results of these investigations will aid in the solution of the problem of utilizing these organisms practically. Extensive work on the conditions in the soil under which the organisms make their best growth, has paved the way for a more detailed study of the organisms and their activities and for a solution of the problem of adding to the nitrogen of the soil by encouraging their growth or adding them to soils not containing them. There has been a vast amount of worthwhile work on this group of organisms following Lipman's lead in this country, and the future holds promise of further and still more important results from such work.

The studies of Lipman, Chester and Stevens, and Withers initiated the extensive experiments in this country on the determinations of numbers of organisms in soils and the activities of various groups of nitrogen-transforming organisms known as the ammonifiers, nitrifiers, and denitrifiers. Chester studied the numbers of organisms in various soils under different conditions; in spite of the inadequacy of the medium employed and the limitations of the tests, his conclusions regarding the occurrence of bacteria in soils and the effects of various factors upon them are still largely supported by later, more extensive studies with presumably better techniques.

Chester made the first so-called bacteriological analysis of soils and in addition to numbers he determined their so-called "zymotic" efficiency or ability to bring about the formation of certain specific products of decomposition. He emphasized the fact that a knowledge of the numbers of organisms in soils is not sufficient but it is also necessary to have information regarding the activities of the organisms to learn anything of their relation to fertility or crop production.

Lipman at New Jersey developed the study of the activities of various physiological groups of organisms in soils, devoting some attention to numbers, however, and developing the synthetic medium for counting bacteria, modifications of which have been used in all the later studies of numbers by plate counts. Lipman early emphasized the fact that the importance of microörganisms in the soil was due to their action and not necessarily to their numbers. His work and that of Stevens and Withers began with the use of the Remy method which had just appeared, and with this method and some modifications of it, extensive studies on ammonification, nitrification, denitrification, and nitrogen fixation were carried out and some interesting and suggestive conclusions were drawn. But difficulties with the method were soon encountered, the chief of which was that it did not permit of a fine enough bacteriological differentiation between soils. About 1909–1910 Lipman suggested the soil or tumbler method at almost the exact time that Stevens and Withers reached the conclusion, from their nitrification studies, that soils must be employed in tests of that process to give an accurate picture of what was occurring in the field. It is interesting to note that tests in soils were first suggested abroad at almost the identical time by Lemmerman, Fischer, Kappen and Blanck, Koch and Petit, and Vogel but work with the method developed more rapidly in this country than in Europe.

Lipman, and Stevens and Withers emphasized the importance of the chemical as well as the bacteriological factors in controlling such processes as nitrification in the soil. Stevens and Withers suggested the terms "N.C." and "N.I.P." for nitrifying capacity and nitrifying inoculating power, representing the same thing as Lipman's chemical and bacteriological factors. The sum of N.C. and N.I.P., Stevens and Withers called "N.E." or nitrifying efficiency. Lipman merely called this the "nitrifying power" of the soil. Similar terms were suggested for ammonification. But although Stevens and Withers'

terms never came into use, in all later work the importance of using soil for testing the activities of microörganisms was clearly recognized.

Lipman's studies embraced ammonification and nitrification, and, in addition to the further development of techniques, considerable information was obtained regarding the occurrence of these processes in field soils and their relation to fertility. He and his coworkers studied the conditions affecting the processes and gathered many facts of technical and practical significance. Lipman also studied denitrification and some of the organisms responsible for the process, following up the studies of Voorhees along this line, which had indicated that the occurrence of the process under field conditions was highly improbable.

As a result of these early studies, bacteriological investigations of the activities of microörganisms in the soil in transforming nitrogen compounds began in various sections of the country, and much valuable information was accumulated. Emphasis has been placed upon the relation between these significant bacteriological processes and the fertility of soils, and it has been found that the character or vigor of these processes in soils may indicate fertility or producing power. In fact, this is usually true, particularly in the case of nitrification. But these investigations, if they did nothing else, very soon led to a general recognition of the dynamic character of soils, a thing which had not been appreciated before and which is most significant in connection with soil management practices and permanent fertility methods.

Lipman in his earlier work also demonstrated the importance of the associative growth of inoculated legumes with non-legumes and found, as did others, that nitrogen may be supplied to non-legumes when they are seeded with inoculated legumes. This work has, of course, a direct bearing on the whole problem of nitrogen fixation by legumes, the methods of fixation, and the form in which the element is fixed.

Mention should be made also of the review of soil bacteriological investigations by Voorhees and Lipman published in 1906 by the Office of Experiment Stations. This summarization and analysis of all the work along soil bacteriological lines did much to stimulate the work in this country.

The pioneer studies of Lipman, Chester, Moore, and Stevens and Withers in the United States certainly have led directly to all the important investigations of symbiotic and non-symbiotic fixation of nitrogen, ammonification, nitrification, and denitrification and of the numbers and kinds of microörganisms in the soil. They have also led to the recognition of the relationship between bacteria and soil fertility or crop production and a permanent agriculture. But this is only a small part of the story. Other developments of the science, almost too numerous to mention, and many of them of almost as great significance have come about indirectly as a result of the inspiration or suggestion derived from these early studies.

The extensive work in this country on cellulose decomposition and more recently on the breakdown of various non-nitrogenous compounds and even

lignins, by microörganisms, may be mentioned. It is very significant. The development of the study of molds, actinomyces, algae, and protozoa has been remarkable, the first two groups of organisms receiving most attention in this country while the algae and protozoa have been studied mainly in England and to a lesser extent over here. Carbon dioxide production in soils has received considerable attention both here and abroad, and its importance as a measure of decomposition processes in the soil and as an indicator of soil fertility has been definitely proved. Methods of studying the carbon dioxide produced under varying conditions have been developed, and the effects of different factors on the process have been determined.

The study of sulfur bacteria and their activities in soils has been carried on to some extent. It has been shown that soils have a sulfur-oxidizing power which is dependent upon various factors peculiar to them. The question of sulfur fertilization of the land is involved here, and the process of sulfofication may become more important in the future, if or when sulfur fertilization becomes a common farm practice. The studies of Lipman and his colleagues on sulfur-rock phosphate composts, besides indicating a method of making a soluble phosphate, suggest much regarding reactions in the soil following the use of sulfur as a fertilizer. Data regarding the sulfur oxidizing bacteria were also obtained in connection with this work.

The importance of microbial actions in making phosphorus available in soils has been investigated. It appears that there is a definite relationship between certain microbiological activities and the production of the element in an available form, from different phosphorus compounds in the soil and from various fertilizer carriers of the element. The phosphorus requirements of microörganisms have been studied, and certain methods for determining the need of soils for phosphates have been based upon the sensitiveness of such organisms as the Azotobacter and *Aspergillus niger* to a deficiency in available phosphorus. The effects of applications of phosphorus carriers upon microörganisms have been shown, indicating that such fertilizers have indirect as well as direct effects upon the fertility of the soil. Other fertilizers have also been studied to determine their relationship to microörganisms. Potash fertilizers, various nitrogen carriers, and certain complete commercial fertilizers have all received attention, and important microbiological changes have been found to occur in soils following their application.

Methods of study have received much attention, and many advances along this line have been made. The development of the microscopic method for determining numbers and kinds of organisms in soils is one of the most significant. Although there is still a definite recognition of the limitations of studies of numbers, many interesting data have been obtained by this method, and further work along this line may lead to many more discoveries of the kinds of organisms in the soil. Mention should also be made of the study of anaerobes which has been under way in recent years. The possibilities of these organisms' functioning in important processes in soils are indicated.

No attempt has been made to indicate all the soil microbiological investigations that have been conducted in the United States during the past 35 years but merely to list the more important phases of the science which have received more or less attention and on which considerable significant data have been obtained. Certainly sufficient results have been mentioned to indicate the great development of the subject of soil microbiology since its beginnings about 1900 in the work of Lipman, Chester, Moore, and others.

It is true that the science attracted most attention both in the United States and abroad early in this century and it may have seemed to many in recent years that there has been less attention to the subject than it deserved. Indeed Waksman in 1925 reported considerable pessimism both in this country and in Germany regarding the development and possibilities of the science. It was pointed out that by 1903–1904 the most significant microbiological processes had been discovered and the causative organisms had been isolated and described and since then no new processes have been found. This is true in the main, but the chief reason for the falling off of interest in the science was the fact that the important results of the studies in medical bacteriology had led many to expect similar radical and far-reaching effects of soil bacteriological research upon practical agriculture. When these expected results of the early studies did not appear and when, outside of legume inoculation, few practical results were suggested, many scientists and practical agriculturists were vastly disappointed and lost interest in the subject. Just why a science should be required to revolutionize existing practices to be considered of significance is difficult to say. And yet that seems to be the attitude of many investigators, some of whom should certainly have a better conception of the real measure of the value of scientific studies and a sound basis for evaluation of such studies.

Furthermore, a lack of appreciation by the workers in the field or by outsiders of the practical application of research results certainly does not mean that the data do not, or may not in the future, have some extremely significant effects upon practice. It merely means that these people cannot yet see the application. Some of the most significant scientific discoveries have remained hidden for years before their practical importance has been recognized.

And then there are those who still claim that nothing new has been added to the science, no new methods have been developed, no new processes discovered since the early days of 1900. Again these are people who are not fully acquainted with the science or who are looking for something new and startling and fail to recognize the potentialities of the results which are being obtained. They seem to expect the startling discoveries of the early studies of a new science to be continued indefinitely. In other words, they expect the impossible.

A careful study of all the work that has been done since soil microbiological investigations began in this country will certainly convince any who are willing and able to analyze the situation that really amazing progress has been made

and that soil microbiology has been put upon a sound basis as a science. The work in this country and abroad has developed in a sound and conservative way, and the brilliant beginnings of the science have been followed by the careful accumulation of facts, the confirmation of the early suggestions, and the broad interpretation of the results. The usual scientific method has been followed, and the results have been gratifying to those who because of thorough interest in the subject and appreciation of the complexity of the science and its ramifications are really soil microbiologists.

All honor to those pioneer students of the science of soil microbiology in this country! They initiated work of great interest and practical value. They provided the foundation for a real science. And the end is not yet. The recognition of the soil as a place of life, as a dynamic thing, is general now as a result of the work of the soil microbiologist. This would be sufficient to justify all the work on the science, if nothing else had resulted. At the present time when national attention is directed to soil conservation and the establishing of a plan for the agriculture of the future it is particularly important that the true character of the soil and the occurrence and activities of microörganisms in it should be recognized and appreciated. And who can predict the results of the future and their value or the practical applications of the work of the past, which may come at any moment?

Soil microbiology is a science of great significance at present and it will continue to be just as important in the future and will, perhaps, become more important. But there is need for more and more study of this fascinating and important science. Much remains to be learned of the processes in the soil, of the relationships between various microörganisms, of the dependence of the organisms upon soil conditions, and of the relations of the different processes to crop growth, to soil conservation, and to permanent agriculture. It is certainly to be hoped that administrators will be sufficiently far-sighted and alert to the true situation, to see to it that investigations along this line are continued and developed and that teachers and research workers in the field will be enthusiastic and inspiring enough to induce some promising young investigators to enter the intriguing field of soil microbiology.

# THE METHOD IN SOIL MICROBIOLOGY AS ILLUSTRATED BY STUDIES ON AZOTOBACTER AND THE NITRIFYING ORGANISMS

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Nearly ten years have passed since the writer first tried to draw attention to the conventionality of the methods applied in soil microbiology. He pointed out that the evidence required in soil microbiology cannot be founded on the classical pure culture method as trustfully as in the case of chemical, industrial, or medical microbiology. Pure cultures of organisms, isolated years ago from the soil, grown on artificial media for an unlimited time on nutrients essentially different from those the original wild species might find at their disposal in the soil, severed for countless generations from the biological conditions of the soil—these cultures cannot tell us much about microbial activity in nature. The utmost the classical method can give us is a few conventional notions only vaguely outlining what really happens.

To improve the method in soil microbiology, the author made the following suggestions:

(*a*) Avoid, on principle, working with stock cultures.

(*b*) Use for experiments strains freshly isolated from the soil by a method as short and direct as possible.

(*c*) Supply them with nutrients that can be supposed to be utilized by them in the soil.

(*d*) Make a special point of studying the reactions of the soil population as a whole, since the competition between its components is the principal determinant of their individual functions.

For these experiments a solid mineral medium was recommended, chemically inactive and perfectly suitable as a vehicle of nutrients for soil organisms: silica jelly.

The writer is ready to admit that considerable progress has been made in leading laboratories since these suggestions were first put forward. Nevertheless, he believes that much remains to be done in this direction, that is, in working out a method more closely adapted to the aims and problems of soil microbiology which center round microbial activity in its natural environment.

To illustrate his point of view, the writer proposes to review critically the methods and results of recent researches on Azotobacter and the nitrifying organisms.

## THE SUGAR AZOTOBACTER AND THE SOIL AZOTOBACTER

For the past thirty years, ever since Beijerinck discovered Azotobacter, it has been grown on sugars, because these substances give the richest cultures. The strains fed on sugar for an unlimited number of years are used for physiological experiments, which always, or almost always, are carried out on sugars, in spite of the fact that since Beijerinck's time Azotobacter has been shown perfectly capable of living on substances of inferior nutritive value. Apparently, microbiologists did not trouble to replace a standard medium by others and thereby risk obtaining poorer cultures. Indeed, from a technical point of view heavy growth seems an achievement, but the agrobiologist has a right to doubt whether in nature the original strain ever has the opportunity to be overfed in a similar way, and whether this overfeeding might not in the long run modify the characteristics of the cultivated strain, particularly its metabolism.

Let us say at once, that the use of glucides as nutrients was not a happy idea from an agrobiological point of view. It has led to a complete misunderstanding of the conjuncture of the activity of Azotobacter in the soil. As Waksman rightly remarks:

> Nevertheless, there is one point not yet settled, namely, whether these organisms (Azotobacter) really fix nitrogen in the soil under field conditions. This has been emphasized by the fact that available energy is not supplied in the soil in the form of mannitol or dextrose universally used in the study of pure cultures . . . but rather as cellulose and other complex carbohydrates, which these organisms are quite unable to use as a source of energy.[1]

For there is no doubt that in their natural environment these organisms never find the opportunity to feed on sugar or mannitol, and that most certainly they derive their energy from very different sources. If such is the case, one is led to suppose that laboratory strains cultivated for innumerable generations on sugars may well have acquired functional characteristics different from those of the corresponding wild strains.

The divergence in the aims and ideas in general microbiology and agricultural microbiology is again made evident by the question of nitrogenous nutrition of Azotobacter. Ever since the beginning of researches on this organism it has been shown that growth occurred more easily on a medium containing combined nitrogen than on a medium lacking it. This became a second way

[1] Translation from the German text: "Jedoch eines ist bis jetzt noch nicht festgestellt worden und zwar das, ob diese Organismen (die Azotobacter) unter Feldbedingungen wirklich Stickstoff im Boden binden. Das ist ferner durch die Tatsache betont worden, dass die dem Boden zugeführte Energie nicht in Form von Mannit und Dextrose, die beim Studium der Reinkulturen allgemein gebraucht werden . . . . zugeführt wird, sondern als Cellulose und andere zusammengesetzte Kohlenhydrate, die von diesen Organismen ganz und garnicht als Energiequelle gebraucht werden können. . . ." Methoden der mikrobiol. Bodenforschung.—*Abderhalden Handbuch der biologischen Arbeitsmethoden*, p. 718. See also: Der gegenwärtige Stand der Bodenmikrobiologie etc. Abderhalden: *Fortschritte der naturwissenschaftlichen Forschung* 10 (1930): 72.

to stimulate its vegetation. The question of how Azotobacter utilizes the different forms of combined nitrogen has been extensively studied. Undoubtedly, it deserved the attention paid to it, but the conclusions that certain authors (Bonazzi, Dean Burk) have drawn from their observations are contrary to reality. They hold, namely, that Azotobacter is an organism which *normally* feeds on combined nitrogen and that it takes to fixation of molecular nitrogen only when artificially forced to it by nitrogen starvation, whereas it has been experimentally proved that in a soil containing combined nitrogen Azotobacter is repressed by rival organisms until it is crowded out and finally smothered altogether (6).

This question will be resumed later in this discussion.

To recapitulate, one is inclined to agree with Waksman in that all research work from Beijerinck's time to 1930 has failed to make the rôle of Azotobacter in the soil any better understood.

## THE MANOMETRIC MICRO-METHOD

In the course of recent years considerable attention has been attracted by the new manometric method, initially worked out by O. Warburg for the study of cellular metabolism. It was Dean Burk who applied the technique to a nitrogen fixing organism for the first time. In his papers he repeatedly points out the advantages of this physicochemical quantitative micro-method over the older chemical methods, which involved nitrogen and sugar analysis: since the experiments with them usually required several days or weeks, it was impossible to maintain constant reproducible conditions. "The ambiguous effects occurring in the case of old and heavy growths, such as . . . . relative lack of nutrients, or complicated mixtures of various stages of life cycles, are avoided." Whereas, with the new technique, "the manometers can be read very frequently . . . . growth and respiration can be determined over very short periods of time (minutes and hours . . . . with an accuracy considerably greater. . . . . In view of the young and highly diluted culture used, one is concerned chiefly with constant, reproducible and, one might say, ideal conditions. . . . . One is concerned with the differentials and not only with the integrals of cell metabolism . . . ." (1, p. 1177).

The writer has quoted from Dean Burk's papers, in order to use his arguments in favor of the new method (1), which are convincing as far as they concern cell respiration and cell metabolism. Expertly handled by Dean Burk and others, the new method has led to some remarkable contributions, such as the importance of calcium for the fixation process, the rôle of humic acid in making iron available, and the relation between respiration, growth, and nitrogen fixation.

Fully aware of the advantages of the new method where problems of physiological chemistry are involved, the agrobiologist, nevertheless, ventures to inquire whether the new method will bring us any nearer to solving the problem of the activity of Azotobacter *in its natural environment* than did the old one, which has left it at a dead point.

The writer thinks the answer is in the negative. If anything, there is even less chance of coming nearer the required solutions by the new method than by the old one. The reason for this is of itself obvious. In the new method stock cultures are used for the experiments, which are performed with sugar as nutrient and with pure cultures exclusively, eliminating thereby biological conditions just as in the old method, with the difference that here only young cells are dealt with, and, furthermore, these are shaken up continuously during the short time the experiment lasts. The conditions, perfectly uniform as they are, appear too narrowly limited and artificial to allow for investigating the functions of the organism more or less completely. Even taking for granted that an Azotobacter cell possesses reactions peculiar and inherent to its protoplasm, still one cannot go so far as to admit that they are absolutely independent of external conditions; otherwise, this would mean a negation of the long established fact of morphological and physiological variation under the influence of these conditions.

With these considerations in mind, the writer would prefer to keep to the general lines of the old bacteriological method, the real object of which is the integral function, rather than the differential, and this by using a method based on the principles indicated in the foregoing.

Finally the writer would like to lay stress on the fact that the true character of the activity of Azotobacter will never be revealed by chemical and physicochemical means alone, without taking the biological factor into consideration; that is to say, without studying the behavior of this microörganism in its natural environment as part of the microflora of the soil as a whole. This side of the question has not had the good fortune to attract much attention. We will begin with it.

## CONDITIONS AFFECTING THE ACTIVITY OF AZOTOBACTER IN THE SOIL

The first observations on the subject date from 1926, (6) and were carried out by the following simple method:

To 50 gm. of sifted soil from a freshly taken sample 0.5 gm. of mannitol is added and the whole well mixed, moistened as required, and spread in a Petri dish so that the layer is about 1 cm. thick. The sample having been previously studied microscopically, the appearance presented by its bacterial population is known, which makes it easy to detect the new growth as soon as it appears after the addition of mannitol. The density of the microorganisms can also be roughly estimated by the writer's microscopic quantitative method described elsewhere (5). It will be observed that the biological reaction in this case nearly always starts by a growth of bacilli attaining a density in the medium of several tens of millions in the first 24 hours at 30°C. This first growth is markedly more abundant in the case of a fertile soil than in that of an unfertile one. After 48 hours, however, the appearance of the culture will be found to have changed considerably: the bacilli will now be difficult to find, as they are crowded out by Azotobacter, of which the density can roughly be estimated at several hundreds of millions per gram of soil. During the third and fourth day the Azotobacter growth reaches two to three billions per gram. The soil and soil solution are filled by the organism, and the earth particles are coated with its mucilage.

These and similar observations lead to the conclusion that if energetic material containing no available nitrogen is added to a well-aerated soil, it has the effect of stimulating Azotobacter growth only, almost all the other parts of the bacterial population remaining at rest. A bacillary form seems to make an exception to this rule, but its scanty and short-lived growth has the evident effect of using up any trace of combined nitrogen the soil might have contained. These are precisely the conditions most favorable to Azotobacter growth. All other species being now eliminated from competition because of the lack of available nitrogen, the organism can avail itself of all the nutrient and multiply freely.

The correctness of this interpretation is further proved by a similar experiment, where small quantities of nitric nitrogen were added to five 50-gm. portions of soil in five dishes, in the following percentages of nitric nitrogen to glucose (5):

(*a*) 0, (*b*) 0.5, (*c*) 1.0, (*d*) 1.5, (*e*) 2.0.

The results were as follows:

(*a*) Density of Azotobacter growth after 72 hours, 2 billion per gram of soil.

(*b*) Abundant growth of bacilli. After 48 hours Azotobacter appears, starting with a few individuals, attaining a density of 75 million per gram of soil after 72 hours.

(*c*, *d*, *e*) All three portions crowded with bacilli only. Azotobacter does not appear at all.

The foregoing experiment shows decisively that the presence of very small quantities of combined nitrogen has the immediate effect of altering the whole nature of the bacterial population of the soil: the smallest dose of nitrogen added—5 per 100,000 the weight of the soil—was sufficient to retard the growth of Azotobacter and reduce its density to $\frac{1}{2^{15}}$ of what it would be without the addition of nitrogen; whereas larger quantities suppressed all development of this fixation agent (6).

In 1932, the author resumed the question while working out a general method for studying the biochemical activity of individual organisms or groups of organisms belonging to the soil population without dissociating or isolating any of them (9). Silica-jelly plates impregnated with different nutrients were simply sprinkled with soil particles. One part of them received fixed nitrogen, the other did not. Azotobacter colonies appeared only on the second lot, the first showing diverse vegetation but never any Azotobacter growth. This happened unfailingly with every kind of energy-supplying material used.

If, as it follows from these two sets of experiments made by means of two different methods, Azotobacter can hold its own only in soils where available nitrogen is scarce or lacking, then nitrogenous fertilizers of any kind would be inimical to its growth in the field. Regular and abundant dressings would tend to reduce its density or even make the species disappear altogether.

The writer knows of only two attempts to investigate the foregoing question. One was made by himself with Madame Ziemięcka (7); the other, by Madame Ziemięcka independently, using the same method (12).

Ten samples from the Experimental Vine-Growing Station at Grammont near Montpellier were sent to the laboratory under their plot numbers, but with no indication as to treatment received by them. The question on hand was to determine the density of Azotobacter in these samples (known to harbor this organism) in relation to the treatment received by the plots. The following counts were obtained on large silica-jelly-mannitol plates (20 cm. diameter):

| *Number of plot* | *Count per gram of soil* |
|---|---|
| 3 | 12,000 |
| 4 | 2,000 |
| 21 | 600 |
| 6 | 500 |
| 9 | 420 |
| 8 | 400 |
| 2 | 360 |
| 12 | 170 |
| 16 | 60 |
| 18 | 0 |

The treatments to which the plots had been subjected for 6 years follow: Number 3 was dressed with mineral fertilizers only, none of which contained nitrogen. Number 4 is a control plot, and had had no dressing at all. The rest of the ten plots received yearly 80 kgm. of nitrogen per hectare—40 as dried blood, 20 as powdered horn, and 20 as potassium nitrate.

The counts show the harmful effect of nitrogenous fertilizers.

In the three last plots ammonium sulfate was used instead of the nitrate, causing a degree of acidity sufficient in this poorly buffered soil to strike the last blow to the Azotobacter population, which in Number 18 falls to zero.

More extensive tests were carried out by Madame Ziemięcka (12) on the classical fields at Rothamsted, which afford, as the author acknowledges, "a unique opportunity for testing methods of microbiological soil analysis, since on them results can be correlated with manurial treatment and with yield data extending over a longer period than is obtainable elsewhere." In all, 79 samples were tested, all taken from the Rothamsted plots. The samples from Broadbalk, especially, were examined three times in the most thorough manner possible. "The best conditions for Azotobacter growth on all three occasions were found in plot 5," says the author, "which received complete minerals but no nitrogen. . . . . The most striking feature of Broadbalk samples was the repression of Azotobacter in plots receiving mineral nitrogen. . . . . The counts made on silica-jelly show an inverse relation between the Azotobacter numbers and the nitrogen dressing. Even on the dunged plot the number of Azotobacter colonies was much reduced and was lower than the control plot when the latter's phosphate deficiency was made up."

Since tests of samples from other fields at Rothamsted gave similar results,

the writer is led to make the general conclusion that in soils treated with 86 pounds or more of mineral nitrogen, the test usually showed little or no Azotobacter growth, even in the presence of phosphate and calcium carbonate; this failure was probably due to the paucity of Azotobacter cells, originally present in such samples.

Here, then, is an instructive example of an error which disregard of biological conditions may lead one into making. Molecular nitrogen, the observer thinks, is not essential to Azotobacter, since this organism grows much better on fixed nitrogen. This might come to be considered as the *normal* condition for its growth. Conversely, growth is slower when the organism is obliged to assimilate nitrogen gas, this latter case might then be considered as *abnormal.* In nature, Azotobacter is forced by bacterial competition into leading this hampered existence almost constantly, for only in this way can it appropriate its part of the energy-supplying material. The reason for this easily verified fact is to be sought in its rate of multiplication, which is much slower than that of the bacilli. Consequently, Azotobacter can avail itself of the nutrient only when multiplication of its antagonists is paralyzed by the lack of nitrogenous compounds. In other words, the biochemical forces of the soil come into play, starting to fix nitrogen only when the soil becomes poor or deprived of nitrogen compounds, but the process is arrested as soon as the rate of the nitrogen fixation reaches a certain level, always relatively low.

This law, when confirmed as such, will perhaps one day make the farmer think over the fact that in paying for the nitrogen in fertilizers he deprives his land of nitrogen which nature gives him for nothing.

This lagging behind in the competition with other organisms must be considered a marked negative characteristic, because of which the organism has to feed on nutrients of inferior quality. As can be seen from the evidence on the decomposition of vegetable matter in the soil, brought out by Waksman, soluble carbohydrates accompanied by proteins, amino acids, or even ammonia and nitrates are very rapidly decomposed in the soil, and it appears certain that the bacilli alone bring about the process as long as the supply of complete nutrients, i.e., available carbon with a suitable proportion of available nitrogen, is not exhausted. The process slows down when the turn of the vegetable skeleton comes—cellulose, hemicellulose, lignin—, and it is at this moment that available nitrogen becomes scarce. Vegetable matter is poor in nitrogen, which is then drawn from the soil, thereby creating areas very poor in, or entirely deprived of, available nitrogen but rich in the usual waste products of fermentation—fatty acids and alcohols—, of which Azotobacter is left in sole possession. Because the medium lacks available nitrogen, no other organism can dispute them. Hence the conclusion appears inevitable that these waste products are the usual nutrients used by Azotobacter in the soil. Indeed, the organism is known to grow on them readily—though less abundantly than on sugar—, and to fix nitrogen.

The chemical energy of the organism seems extraordinary, when one con-

siders that it thrives on benzoic salts—a fact established by the writer—, showing abundant, typical, and pure growth. Whether benzoic acid occurs in the soil, as a waste product of lignin decomposition, for instance, is not known, but it is not improbable. This may or may not be, but the writer by the use of benzoic acid has devised one of the most efficient and direct methods for isolating Azotobacter from the soil, which will now be described.

### THE BENZOATE METHOD

If the question does not go beyond making Azotobacter counts in the soil or controlling its capacity for nitrogen fixation, mannitol and sugar are almost as good as, or sometimes better than, any other energy material. But they are not suitable where direct and rapid isolation of the organism in a state of purity is required for use in experiments on biochemical questions of the kind about to be discussed. As is known, Azotobacter growth on sugar and mannitol is never pure, and, consequently, repeated replating and reinoculation are indispensable. The use of a micro-manipulator on mixed material does not help much to get rid of impurities. Therefore, if stock cultures are to be avoided, direct isolation from the soil can be successful only with the most selective medium. The author thinks benzoic salts are best suited for the purpose.

Pure commercial sodium benzoate and calcium benzoate, free from salicylate, recrystallized once or twice may be used. The doses of the salts are as follows: sodium benzoate, 0.1 gm. to 30 cc. of silica-jelly in a 10 cm. diameter Petri dish; 0.5 gm. of the salt to 150–200 cc. silica-jelly in a 20 cm. diameter Petri dish. For calcium benzoate the doses are smaller: 0.05 gm. and 0.3 gm. respectively.

It is not advisable to raise the dose beyond the figure indicated. To keep solutions of these salts ready for use will be found convenient, the concentration being: 0.1 gm. sodium benzoate or 0.03 gm. of calcium benzoate to 1 cc. of solution.

Further details about the preparation of the plates are given elsewhere (1, 9).

They are inoculated with a very small quantity of soil from a sample known to harbor Azotobacter, by sprinkling the soil particles over the whole surface through a Gooch crucible. The crucible can be weighed before and after the operation to ascertain the exact weight of the soil used, should this information be needed. This weight ought not to exceed one to a few centigrams.

Conspicuous colonies of Azotobacter appear during the second day of incubation at 30°. Examined under the microscope without delay, they will be found to consist of both the larger and the smaller forms of Azotobacter, the majority quite pure, others containing a few isolated rods. When the best colonies are picked out, they must be reinoculated at once in order to get rid of amoebae, which would otherwise multiply and ravage the cultures.

Sometimes, in order to have inoculation material ready to hand, and also with a view to economizing plates, it will be found convenient to inoculate

some liquid cultures. The composition of the solution is similar to that of the plates: namely,

| | | |
|---|---|---|
| Calcium benzoate | 10 cc. = | 0.3 gm. of |
| Nutrient salts solution | 10 cc. | the salt |
| Solution of humates | 10 cc. | |
| Tap water | 170 cc. | |

Fifteen cubic centimeters of this solution to a 125-cc. Erlenmeyer flask will form a layer a few millimeters deep.

For nitrogen fixation and other experiments, pure colonies sprung up round the earth particles are used. A suspension of them is made in sterilized tap water, and enough of this is poured over the plate to moisten the whole surface. When control plates are necessary, they are given the same quantity of suspension and immediately treated with chloroform vapor in a closed receptable. This way of inoculating over the whole surface has the advantage of shortening the time the plates need be kept, which must not exceed 96 hours. Mannitol or calcium lactate silica-jelly plates can be inoculated in an exactly similar way in cases where particularly heavy growth is required for subsequent analyses.

The development of the organism on benzoate plates is quite regular and highly characteristic. Slightly milky at first, the colonies grow opaque with age and take on a chocolate-brown color after 3 or 4 days, the whole of the jelly turning a smoky black.

These features are particularly pronounced when the plate carries only a few colonies, for when a sodium benzoate plate is entirely covered with Azotobacter mucilage the jelly becomes slightly liquefied because of the alkalinity of the medium.

Under the microscope during the first and second day the growth is seen to be composed of elongated cells in pairs or short chains; by the third day, rounded individuals are decidedly predominant; on the fourth, only rounded, blackened, and encapsuled forms are seen, which represent the resting stage of the organism. The general impression is of regular and normal development. Involution forms, frequent in cultures on glucides, are never found.

For analysis, the plates are put to dry, after the jelly has been flooded with 2 cc. 0.1 *N* HCl to avoid loss of ammonia. If they are to be Kjeldahlized, the scales of dry silica are transferred to a Kjeldahl flask and the dishes washed out with a minimum of water using a glass rod tipped with a policeman.

The nitrogen fixation on this medium was proved by the macro-Kjeldahl as well as by the micro-Kjeldahl method. The latter is certainly preferable; especially with the use of a Parnas and Wagner distillation apparatus, as recommended by Pregl. Difficulty is sometimes experienced when the dry silica to be burned exceeds the convenient volume for the capacity of a micro-Kjeldahl flask. In that case a macro-Kjeldahl is used, the product of combustion is made up to 100 cc. with distilled water, and 20-cc. portions of this are distilled.

The average figure for all determinations made is 11 mgm. of fixed nitrogen per gram of benzoic ions, i.e., a little more than in the case of mannitol and glucose cultures, where it is generally less than 10 mgm. under identical conditions.

To recapitulate, the writer believes that the benzoate method provides the means for operating with Azotobacter taken directly from the soil, and that with a better chance of its being pure and authentic than when taken from stock cultures.

Certainly, in the material thus isolated several strains may be mixed, and, consequently, further manipulations are needed if a particular strain is wanted. In the latter event it is best to have recourse to a micro-manipulator. If it be objected that it is less trouble to take ready stock cultures labelled *chroococum, agilis, vinelandii,* etc. than to make a fresh isolation, the writer believes that the labels do not, by far, always correspond to the characteristics of the original species and that a thorough control of the apposed diagnosis is not often an easy task.

## AMMONIA SYNTHESIS

The writer does not think it necessary here to review once more the history of ideas prevalent on the chemical mechanism of fixation. Suffice it to say that the synthesis of ammonia by direct combination of hydrogen and nitrogen —a hypothesis nearly a century old, for it was first advanced by de Saussure—, was considered by the majority of students most probable from a theoretical point of view. Does not the *model* of chemical industrial synthesis of ammonia based on catalytic action suggest an analogous process in the case of biological synthesis?

It must be admitted that the experiments performed during the last quarter of a century failed, in spite of their very great number, to find conclusive evidence to support this hypothesis until 1930. Traces of ammonia have been occasionally observed by some authors, but then they give no precise data as to the nature of this ammonia liberation or the conditions on which it depends.

Ammonia being one of the commonest products of decomposition, a different origin, even if probable, is not easy to trace. Without a very close microscopic examination of the culture it is not possible to decide whether ammonia liberation is the result of some degradation process, caused by attacks of foreign organisms or by cell autolysis. Then again, should any ammonia appear, to start determining it after the culture has been incubated for an arbitrarily fixed number of days will not help to decide whether it is produced by young, adult, or old, and perhaps degenerate cells. In papers published before 1930 these very data are missing. As to the origin and characteristics of the cultures used, only mention is made that they were stock cultures labelled *A. chroococcum, A. agilis, A. vinelandii.*

On this subject a paper by Kostytchew, Ryskaltchouk, and Schwezowa attracted most attention (3). The authors had found considerable quantities of ammonia and amino nitrogen in their cultures of *A. agilis* and did not hesitate to consider it as the first tangible product in the process of synthesis.

Do their experiments support this conclusion? The writer thinks not. It is enough to say that the fact that analyses of their liquid cultures were made after 10–15 days and even after 20–25 days makes the origin of the ammonia found quite uncertain. Nothing is said about the microscopic characteristics of the growth in their cultures. Did they find it pure after such a long period of incubation? Was it free from autolyzed cells? There is only mention that the stock culture used was labelled *A. agilis* and was obtained through the courtesy of a colleague. The quantities of nitrogen found in the solution were considerable, for example: one culture contained 13.4 mgm. total nitrogen, of which 12.4 mgm. was ammonia nitrogen; another culture contained 10.7 mgm. total nitrogen, of which 4.9 mgm. was ammonia nitrogen and 6.5 mgm. amino nitrogen. The presence of the latter was proved in all the cultures, and it is hard to admit that it is due to anything but the degradation of cell proteins. True, the authors insist on the analogy between reduction processes brought about by Azotobacter and the reduction of nitrates by molds, the products of which, ammonia and amino nitrogen, accumulate outside the cells only in the surrounding culture solution; this, they suppose, would be the case with the products of nitrogen fixation by Azotobacter.

If this were true, bacillary growth would easily crowd out Azotobacter growth under natural conditions, as has already been described. Now, nothing of the kind is observed on plates inoculated with soil. Similarly, according to Dean Burk's findings, *Aspergillus niger* does not grow in nutritive solutions after Azotobacter has been grown in them, unless traces of available nitrogen have been added to them.

Lastly, if the production of such noticeable quantities of ammonia is a regular phenomenon, an explanation must be found of the contradictory results obtained by the very great majority of investigators who have not detected any ammonia whatever. The contradiction would be easier to understand if a new culture method were applied more sensitive for the detection of ammonia production, but this was not the case, for the authors kept to the old standard method for growing Azotobacter in solution.

These criticisms have already been formulated in a communication made by the writer to the Académie des Sciences on March 17, 1930 (8). He insists that he has not observed ammonia production in his very numerous cultures on mannitol media, but he goes on to say:[2]

> This negative result cannot be considered as a proof against the hypothesis of hydrogenation of molecular nitrogen, for it is enough to imagine a state of perfect equilibrium between the processes of ammonia synthesis and ammonia assimilation, to understand why it is not

[2] Author's translation from the French (8, p. 662–663).

detected in a free state. It is a question, then, in the present problem, as in others dealing with analyses of microbial processes of discovering the particular conditions which would throw the phenomenon out of equilibrium in order that we may intercept its primary products. This could be attempted in two ways; namely, by applying means to prevent the ammonia from entering into combination, or in repressing the plastic or assimilatory process in the cells. If the hypothesis of the hydrogenation of nitrogen through microbial activity is well founded, an accumulation of ammonia should be the result. The ordinary way to free ammonia would evidently be to raise the alkalinity of the medium as far as possible, but not enough to impede the growth too seriously. . . . The simplest and surest way to obtain this is to let Azotobacter bring about this reaction for itself by growing it on silica-jelly impregnated with organic sodium salts, lactate or succinate, but with no other addition than mineral salts. The destruction of acid ions is so rapid in these conditions, that the initial pH of 6.8 — 7.0 rises . . . in two days to 9.0 and above.

Under these conditions by fixing a strip of red litmus paper inside the lid of the Petri dish, or by Nesslerizing water drops condensed on the lid by slow distillation, which can be made more abundant at will, ammonina production can be observed most easily without disturbing the culture. In silica-jelly plates of 20 cm. diameter impregnated with 2 to 2.5 gm. of lactate or succinate, after incubation for 5 days, ammonia accumulates mostly at the rate of 3 mgm. per plate, determined by the aeration method without alkali.

Only material directly isolated from the soil according to the method described in the foregoing was used for the experiments. The cultures were carefully examined under the microscope every day, but neither impurities nor autolyzed cells were found.

These observations were then described in detail by the writer in a paper on the subject published in 1932 (10). However, to keep strictly to the chronological order of publications, a second paper by Kostytchew et al. (4) which appeared in 1931 in the interval between the two papers by the writer will first be reviewed.

The authors evidently knew nothing about the publication of the first of the two, since they do not take any of the data into consideration, nor even mention it. In their new paper, they describe a set of experiments that are intended merely to confirm the results of the first set. But their attitude does not seem quite justified in that a different method is applied and the results are not quite the same.

This time they use the method the writer described in his previous papers (1926–1929), namely, making their cultures in 20 cm. diameter Petri dishes with mannitol silica-jelly. The dishes are inoculated with a strain of Azotobacter recently isolated from a soil in the Crimea, and sometimes, apparently, also with earth particles *in natura*. If they do not follow ammonia liberation continuously, they begin analyzing their cultures after a short incubation of 2, 4, and 6 days, consequently using young growth only. Finally, a careful microscopic examination is mentioned.

The quantities of ammonia are found to be as low as a fraction of a milligram for a 2-day-old culture, 1–2 mgm. for a 4- to 6-day-old culture. Nothing is said about finding any amino nitrogen.

So far the results are sound, and the only interpretation is that the ammonia found is due to a process of synthesis: the only possible conclusion where young, active nitrogen-fixing cells are concerned.

Together with this now well-established fact, however, a new observation is announced, namely, that only the ammonia found in young cultures before the carbohydrate is consumed is due to synthesis, whereas ammonia produced by older growth, when the nutrient is already exhausted, is formed by desamination of the cell substance. This view of the question is again suggested by an analogy with molds, where Kostytchew ascribes a double origin to the ammonia found by reduction of nitrate: a primary production by this reduction and a secondary one, which sets in after the disappearance of sugar by desamination of the cell plasma. A similar fact is admitted in the case of Azotobacter: primary ammonia—a product of synthesis, secondary ammonia —a degradation product.

It is clear that the only way to prove irrefutably that this desamination process really does take place would be to keep an exact balance of the nitrogen in the cells and in the solution, from which a progressive loss of the former could then be estimated. This too difficult experiment is not attempted by the authors; they merely state that "another mode of ammonia production is not possible in this case." To support this conclusion two sets of experiments are performed: (*a*) To plate cultures incubated for 8 days and containing appreciable quantities of ammonia a fresh portion of sugar is added: this has the effect of lowering the rate of ammonia and considerably raising the amount of total nitrogen; (*b*) by growing Azotobacter on a dilute solution of peptone and glycocol, a considerable amount of ammonia was produced in the absence of mannitol only, whereas the presence of this nutrient had the effect of lowering it to slight traces. Both experiments are supposed to show that Azotobacter can really bring about desamination of amines and proteins, which sets in after the destruction of the carbohydrate nutrient.

In the writer's opinion, the aforementioned experiments do not provide a definite proof of desamination, the less so since ammonia liberation by old growth can be explained, at least in part by a different process, which will be discussed hereinafter. The correctness of Kostytchew's assertion is all the more subject to doubt, as this author himself expresses two contradictory opinions on the question: in his first paper he negatives any desamination by Azotobacter; in the second, he affirms that the organism is a powerful desamination agent.[3]

The writer's memoir on the synthesis of ammonia by Azotobacter, published in March 1932 (10), followed so closely on the second paper by Kostytchew

[3] *Quotations*: First paper "Ausserdem ergab sich dass Azotobacter kein desaminierender Organismus ist, da er selbst in Gegenwart von bedeutenden Peptonenmengen keine Ammoniakbildung hervorruft" (3, p. 6). Second paper "Diese Zahlen zeigen, dass auf Peptone allein grosse Mengen von Ammoniak entstanden sind" (4, p. 111) . . . "Sonst wurde dargelegt dass Azotobacter ein starkes Desaminierungsagens ist" (4, p. 113).

et al., that the writer, in his turn, could not take it into consideration. This memoir describes extensive studies on ammonia liberation, its condition, and its course.

The fact that ammonia easily accumulates in media where it is blocked by fixed alkali, whereas it mostly fails to be detected in ordinary culture media, seemed to show that free ammonia is in no wise a normal, necessary product accompanying Azotobacter growth, but that it may depend on the conditions of growth in general, and on the nutrient offered in particular. A study of the effect of several nutrients of a different kind on ammonia liberation was then planned. Mannitol, glucose, and calcium lactate were tried out under strictly parallel conditions with organic sodium salts, such as lactate, succinate, acetate, butyrate, and propionate. Finally, ethyl alcohol and normal butyl alcohol were used.

It was found that on substances of the first group, which are the better or the best energy materials, ammonia appears late and only in traces; sometimes it is even difficult to detect. Whereas, on poorer nutrients, particularly fatty acids and alcohols, ammonia accumulates more easily, to the extent of some milligrams to a large plate in a few days.

All these observations lead to the general conclusion that the process of nitrogen fixation occurs in two phases, of which ammonia synthesis is the first, and its assimilation, the second, and that these two processes may not always be well balanced. The more active is the growth, the more intense will be the ammonia consumption. On the other hand, every impediment to good growth, whatever its nature may be, whether inferior quality of nutrient, or the lack of it altogether, or any other unfavorable condition, can be supposed to lead to a slowing down of ammonia utilization, which would cause ammonia to be discharged into the medium. Thus it would follow from this assumption that in the soil, where Azotobacter can find only inferior nutrients and where the supply is periodically insufficient, the conditions are such as would be particularly favorable to ammonia liberation.

When the writer's results are compared with those in the second paper by Kostytchew et al., it will be noted that the latter obtained ammonia production on mannitol far more easily than did the writer. This difference should not be looked upon as a contradiction, for as the strains used were of a different origin (France and the Crimea), the fixation process for each might well have been regulated differently.

The experimental data are, as already has been remarked, insufficient to decide whether ammonia liberation in old cultures due to desamination, according to Kostytchew, really takes place. But there is another fact that singularly complicates the question. Desamination, as this author insists, is a vital phenomenon (Lebenserscheinung) which is suppressed by toluol. The writer's attention was attracted by the fact that Azotobacter cells dried and ground up with sand and glycerol, or killed with chloroform, toluol, or ether, continue to

liberate traces of ammonia for a long time. If such is the case, then the idea of a special catalyzer, or synthetic enzyme, which can be isolated from the cells appears to be plausible. This same enzyme may be supposed to function in living cells, be they young or old, producing ammonia, which because of lack of nutrient is no longer drawn off from the old cells into the synthetic process and escapes into the medium.

It is not the writer's purpose here to go into a detailed discussion of this most difficult problem, but only to give a brief critical review of recent investigations, just so far as is necessary in order to outline its present state and to do away with certain misunderstandings.

The writer is inclined to think that his observations of the fixing organisms, where they appear to act as generators and carriers of a synthetic enzyme, will turn the study of the whole problem of biological fixation on a new line that may lead to a clearer understanding of this form of activity.

As a corollary to this review, it emphasizes the fact that the work of Kostytchew et al., and the writer's, executed independently one from the other, though using the same method, lead to an identical conclusion, namely, that the fixation of molecular nitrogen by Azotobacter is a reduction process leading to a synthesis of ammonia as a primary product, or one of the primary products of the reaction.

Opposed to this view is a quite different theory, of which Dean Burk is the author. He insists particularly on the fact that all his efforts to detect ammonia in his Azotobacter cultures proved unsuccessful (1, p. 1188): "1. Liquid portions of centrifuged cultures were found to contain no nitrogen, by the Kjeldahl method. 2. Aklaline distillations of 10 cc. portions of more than 200 Erlenmeyer flask cultures, grown over a great variety of conditions and ages (up to four months) yielded no trace of ammonia, amines, or other volatile nitrogen bases (less than 0.01 cc. N/100 N, or .0014 mg. of N). 3. Four strains of Aspergillus niger molds made no growth when inoculated into cultures of several strains of *Azotobacter chroococcum* regardless of the latter's ages (i.e., up to four months), whereas if traces of fixed nitrogen were given these same mold-inoculated cultures, growth was prominent in less than 24 hours. *Azotobacter chroococcum* cultures of any age, made alkaline with potassium carbonate, could be distilled in steam in a Pregl micro-kjeldahl apparatus for at least half an hour and doubtless longer without yielding volatile bases. 4. More than 200 cultures (as above) were tested by the usual and most sensitive oxygen-nitrogen and oxygen-hydrogen test reagents. . . . with entirely negative results."

The tests, as can be seen, are very careful and numerous. Nevertheless, as a general rule in scientific researches negative facts cannot counterbalance positive ones, when the latter are sufficiently numerous and precise as in the present case. The objection seems then justified, that the student had not had the good fortune to chance on a method suitable to bring out the positive result in question.

Again, it is to be remembered, that a total lack of ammonia production does not contradict the writer's theory, for the balance between production and consumption of ammonia can be constantly at nought. It seems quite possible, that this is the rule with certain strains of this microörganism, especially with stock cultures containing what the writer calls the sugar Azotobacter.

There would be nothing more to say about the negative facts already mentioned if Dean Burk's theory about "Azotase and Nitrogenase in Azotobacter" (2) were not based on them, i.e., on the non-production of soluble nitrogen as an essential condition. According to this theory, the activity of Azotase, an enzyme system, is normally limited by the extent of growth. Termed *phyoenzyme*, it is growth bound, that is, correlated with the structure of the living cell to the extent that the velocity of the formation of the (intracellular) reaction product parallels, and is normally limited by, the velocity of growth. The elaborated nitrogen compounds occur in the cell bodies, chiefly as proteins, and are not ordinarily liberated into the culture medium by young and active cultures.

The quotations show how vastly different the fundamental ideas are from which the two theories have sprung. Without going into a criticism of the data of the physicochemical paper (2) where this theory is developed, the writer believes that the facts described in the present paper are in distinct contradiction to the theory about Azotase.

## THE NITRIFYING ORGANISMS

After the writer's researches on nitrification (1890–1899), numerous careful investigations were made in order to control the data obtained by him. Excepting perhaps some criticisms of details, these data found general confirmation. A review of this collective work is given elsewhere (11). Here it will be sufficient to remark that these studies (1900–1932) were carried out mostly in two directions; namely, isolation of the specific organism in a state of absolute purity—a delicate technical operation, which gave investigators much trouble and was not always successful; and influence of organic matter on their activity. Except by those who worked with a heterogeneous mixture of soil organisms, it was confirmed that the nitrifiers are not able to decompose organic nutrients, but that their growth is even repressed by them, even when present in a very low concentration. Readily assimilating carbonic acid, they appeared as perfect autotrophs. In spite of the repeated confirmation of this characteristic, considerable time was spent in proving them rather to be facultative heterotrophs, but without success.

Whether students were attracted by this question because of its relation to general physiology or more as a consequence of technical difficulties, at any rate, the study of the microbiology of nitrification made little progress where questions of agrobiology were principally concerned. The following subjects come under this heading: the isolation and characterization of species or strains from soil samples of different regions; the distribution of the specific organisms

in various habitats (cultivated or uncultivated land, forest soil, swamps, etc.); their adaptation to the conditions of their habitat; the optimum pH for different strains and the influence of the soil pH on their growth in it; methods for determining their density in the soil and the comparison of these densities in soils undergoing diverse treatment, etc. On all these points studies were scarce and were attempted with only indirect methods which could not give clear results.

To open up new possibilities in this domain of research, the writer, with Helen Winogradsky, worked out a new method simplifying the manipulation of the nitrifying bacteria. The method is based on the use of silica-jelly plates *enamelled* with a layer of carbonate of lime, of carbonate of magnesia, or of powdered kaolin (the latter for nitrate organisms). The plates are sprinkled with soil particles; colonies, sprung up round these particles, are reinoculated repeatedly on the same media. Perfectly uniform growth can thus be obtained in a relatively short time, a fortnight or so, quite, or nearly, free from all impurities detectable by careful microscopic examination. Such a state of microscopic homogeneity is quite sufficient for both morphological and agrobiological study of soil nitrification. The culturally controlled purity, which is obligatory in general microbiology and which takes so much time and labor, can be dispensed with. The most important condition for success is a careful exclusion of organic compounds.

Besides being far more efficient than the old, the new method commands better means for dissociating and differentiating strains, for the detection of new species (Nitrosospira), and for direct counts of nitrite organisms in the soil, all of which were almost impossible by the old method. The writer hopes that agrobiological studies on nitrification will be greatly facilitated by it.

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# DEVELOPMENT OF SOIL SCIENCE

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Soil science today is an independent natural science, but this still young science traveled far before reaching its present stage of development. The history of its evolution includes four main periods: (1) Soil knowledge under the influence of the old philosophy; (2) agronomy in the service of agricultural practice; (3) pedology as a branch of geology; and (4) soil science as an independent science.

## THE FIRST PERIOD

It was inevitable that soil as a medium for plant growth should have been an object of man's interest even during earliest times; during this period, much practical experience and knowledge were transferred from father to son through many centuries. The first recorded theories of the nature of soil were formulated by the Greek philosophers Empedocles (440 B.C.), Aristotle (384–322 B.C.), and Theophrastus (373–228 B.C.). According to their theories, material earth was one of the four elements; furthermore, it was supposed that there existed in the soil some fatty material, which the Latin language expressed by "oleum unctuosum." As we shall see, ideas concerning this oily soil constituent, which was later called "humus," can be traced up to the eighteenth century. Columella (in the first century) in his book, entitled "De re rustica," grouped soils according to their appearance. In the "Georgics" of Virgil there is special reference to the oily black soils as one of the many soils mentioned having different colors. But all of these classifications of the ancients were based entirely upon external observations, and were almost entirely lacking in real knowledge of the nature of the soil.

## THE SECOND PERIOD

The first treatise on agronomy to have some foundations upon scientific experimentation was the "Agriculturae fundamenta chimica" by I. G. Wallerius (1709–1785) of the Academy of Upsala. Although this contains only traces of real agricultural chemistry, still it was the first report in the history of agronomy to differentiate between humification and peat formation; to describe some physical properties of clay, sandy, and calcareous soils; and to emphasize the importance of soil research. This initial research was continued by Wallerius' successor, the well-known chemist and mineralogist, T. O. Bergmann (1735–1784), who tested soils chemically, and concluded that in the best soil the ratio of clay:sand:lime:soapstone is approximately 4:3:2:1.

Not only chemists, but botanists as well, were interested in soil classification. It is noteworthy that the great botanist, Linnaeus (1707–1778), classified soils according to their natural vegetation and his nomenclature was adopted widely. In this sense, the same man who founded an ingenious system of plant classification, first detected the close relationship between soil types and natural vegetation. Although very acceptable, the soil system of Linnaeus did not yield any profound knowledge of the different soils, because the chemical experiments with soils at that time were still deficient.

It is characteristic of the status of agronomy in the eighteenth century that the Scotch physician Francis Home (1756–1832), in his treatise on "Principles of Agriculture and Plant Growth," approximately 2,000 years after Theophrastus, still attributed to the "oil" of soil an important rôle, especially in the coherence of loamy and clay soils. Though this book is rich in interesting and careful observations on the crummy structure of soil, the coherence of loam, the water capacity of soil, and the formation of saltpeter in soil, the explanation of the phenomena is incorrect because it lacks any chemical or physical basis.

The Frenchman, I. A. Cl. Chaptal, in his book on agricultural chemistry, written in 1823, treated mainly the physical properties of soil, and the several soil analyses that he made were rather inadequate.

The real basis of agricultural chemistry is found in the works of de Saussure, Davy, Thaer, and Einhof. Though the humus theories of Thaer, of de Saussure, and of others were proved unsound by the clear arguments and experiments of Liebig and his successors, nevertheless the aforementioned scientists contributed much chemical knowledge to soil science. This is especially true of the work of Sir Humphry Davy, who, in his book "Elements of Agricultural Chemistry" (London, 1813), pointed out that agricultural plants obtain their food partly from the soil, especially those mineral elements that are relatively deficient in many soils and that, on the other hand, occur in relatively larger quantity in the ash of agricultural plants than in soils.

Thus, soil research was undertaken especially by agricultural chemists, such as Sprengel and Liebig. The former, in his "Bodenkunde oder die Lehre vom Boden" (1837), gathered together all the knowledge of his time and published about 180 chemical soil analyses. Yet Sprengel treated the field of agronomy from a narrow practical viewpoint, studying how far soil research could contribute to plant production. Similarly, the great master of agricultural chemistry, Justus Liebig (1840), though treating the most prominent plant physiological problems of his time clearly and effectively, considered the soil simply as one factor of plant production.

At that time soil physics was also investigated by the agricultural chemist. For example, Gustav Schübler described all of his pioneer work in soil physics in his book on agricultural chemistry, entitled "Grundsätze der Agrikulturchemie in näherer Beziehung auf land- und forstwirtschaftliche Gewerbe" (1831). The same is true of his successors, among whom are found such promi-

nent scientists as Schumacher, Wollny, King, and investigators in the Bureau of Soils in Washington, D. C., at the time of Milton Whitney. All of these well-known scientific men treated the soil simply as a source of nutrients for plant growth, but not as a natural body worthy of study as such.

There is still another type of investigation in agricultural chemistry which deserves particular mention here. These studies in a field which is partly physical and partly chemical, embrace the phenomenon called "soil absorption." Even as early as 1819, the Italian Gazzeri described this phenomenon, and it was investigated later by Bronner, Huxtable, Thompson, Way, Liebig, Mulder, and especially van Bemmelen. The last published his first experiments on soil absorption in 1888 in his papers entitled "Die Absorptionsverbindungen und das Absorptionsvermögen der Ackererde." These publications represent the first steps in colloidal chemistry, the fundamental importance of which in soil science has become so apparent in recent years.

The first traces of still another branch of soil science are encountered during this period of advance in agricultural chemistry. As is well known, the great master of microbiology, Louis Pasteur, suggested the important rôle of bacteria in the transformation of organic matter in the soil: without these microörganisms all dead organic matter would accumulate on the surface of the earth, and plant growth would suffer from a deficiency of nutrients in a short time. Some of the first investigations in soil bacteriology were concerned with those organic materials which contain nitrogen. A description of the fundamental researches on nitrification and on nitrogen-fixing bacteria is not within the scope of this paper, but the work of Warington, Winogradsky, Demoussy, Omelianskii, Beijerinck, Hiltner, Remy, Lipman, Stoklasa, Löhnis, Waksman, and others, which has undoubtedly developed the field of soil bacteriology, should be mentioned. However, their investigations were primarily concerned with problems in the field of agricultural production, as were the researches in the other branches of agronomy during this second period of development of soil science.

It is fitting to mention here Müller, Wollny, and Ramann, who have contributed valuable information on the natural formation of humus and have made other studies of benefit to soil science. The names of Mulder, Grandeau, Tacke, Baumann, Gully, and Sven Oden are also encountered in the research on the chemistry of humus.

Although these different branches of soil science developed nearly side by side, but independently of one another, they served a common end—agricultural production. Just as the agricultural chemists conducted their research work in the service of agricultural production, so also the other branches of soil science were devoted to a similar purpose. Therefore, this period of agricultural chemistry may be differentiated from the next period, that of interest in the geological phases of soil science, though research in both fields had been progressing side by side for some time.

### THE THIRD PERIOD

The German geologist, Fallou, was the first to recognize that the soil itself is a natural body worthy of investigation. It was Fallou, himself, however, who introduced soil science to the field of geology. In this connection, the following quotation from his work is of interest: "Können sich doch nicht einmal die Lehrer der Bodenkunde von jener merkantilischen Betrachtungsweise frei machen, denn sie denken sich den Boden nimmer vor allen Nebenbegriffen abstrahiert, sondern immer nur als Acker der seine Rente tragen muss. Es fehlt an einer wissenschaftlichen Bodenkunde die diesen Namen verdient." Still in his "Pedologie oder allgemeine und besondere Bodenkunde" (1862) his soil classification has a strictly geological-petrographic basis. It is to his credit, however, that he delivered soil science from the shackles of practical domination, and established the scientific basis of agrogeology and soil mapping.

He may have had the correct intention, but as a geologist been led to a geological classification of the soils of his own country; since the relatively narrow region he surveyed was close to the forested region, the local geological agencies differentiated the soils from one another. Shortly afterward his compatriot, M. Fesca, in his book "Die agronomische Bodenuntersuchung und Kartierung" (Berlin, 1879) agreed that geological data are not sufficient scientific standards for the desired classification and characterization of soils. Nevertheless, agrogeology was a good medium for the development of soil mapping on a larger scale than had existed previously. During this period, agricultural chemistry, because of its numerous defeats in the field of practical agriculture, gradually lost its dominant position in research in soil science.

During the last two decades of the nineteenth century a new series of experiments was introduced in Germany by Hellriegel, Wagner, Maercker, and others; these were the so-called "pot experiments." The results were particularly instructive and aided practical agriculture where agricultural chemistry had failed. It may be well to mention here the many disappointments that attended the practical use of chemical analyses of soils. In the so-called "golden age" of agricultural chemistry, it was believed that by the use of chemical analysis it would be possible to give more exact recommendations for fertilization, just as analytical procedures had aided in the manufacture of fertilizers. The methods and principles used at that time in soil analysis, however, brought complete failure. The result of this disappointment, combined with the positive indications of the pot experiments, led to the creation of a general opinion that chemical analysis of soils might be instructive for scientific research, but had no use in practical agriculture. This was the general situation at the beginning of the present century. Only a few prominent chemists such as Déhérain, Schlössing-fils, Gerlach, Dyer, Hilgard, and some others, had not given up hope of finding new promising uses for soil chemistry.

In place of chemical analysis, mechanical analysis, which seemed very promising for characterizing soils physically, was adopted more and more in soils laboratories. Results of mechanical analyses combined with the information from geological and petrographic determinations were commonly obtained in soil research, and these served more or less as scientific criteria for soil classification, nomenclature, and mapping. The soil maps of the "Preussische Geologische Landesanstalt" at Berlin in the first decade of this century represent, perhaps, the best of this type of work. As a result of these tendencies, soil mapping and scientific soil research seemed to be heading toward complete incorporation with geology, with that phase which treats of the surface geology of the earth; in this way it would become but one more practical branch of the geological survey.

In the United States, however, soil surveying was principally centralized under the head of the Bureau of Soils of the Department of Agriculture and was organized to consider the entire country. Mechanical composition of the soil served as the basis for physical characterization, but the real geological characteristics were neglected more or less, since no general relationship was found to exist between the geological origin of the soil and its practical behavior. Petrographic and mineralogic analyses were also considered for use in classification, but not with very promising results; both are too complicated for use in surveying soils. A somewhat subjective method of classification was introduced, however—subjective in the sense that the soils described were different soil series or local types, which had local practical characteristics; a single soil could be sometimes identified by the surveyors with other local soils. For surveying and mapping soils locally this was a fairly feasible procedure, and for practical purposes had much merit as a means of directing the farmers in uniform mass production. Each bulletin, published with the soil map, was an agricultural guide which stated how to produce the best crops on the various local soils. Since these reports were closely correlated with experiments on the local soils and with climatic and hydrographic conditions, they should reflect well the general agricultural conditions of the surveyed land. In these respects the soil maps might be expected simply to serve agriculture but to lack scientific value; such, however, is not the case. They indicate in general that neither the geological origin nor the textural composition of the soil is the general factor in these local soil types that determines their agricultural fertility.

There was still another method of soil surveying practiced in Russia. The founder of this agronomic school was Dokuchaiev (1897), who treated soils as a function of various soil forming factors. He and his successors have developed a new system of soil classification, nomenclature, and soil mapping, based principally upon climatic factors and morphological characteristics. Since this research led to the development of an independent soil science, it may be well to delay its treatment until a consideration of the next period of this historical sketch. However, this Russian zonal classification of soils

should not be confused with the climatic zonal rock weathering introduced by Richthofen. The soil classification of Richthofen actually had a geological basis; he treated soils simply as products of rock weathering and not as a function of all soil-forming factors. It is true that by considering climatic zones in rock weathering, Richthofen introduced at the same time another primary soil forming factor. On the other hand, the soil zones in Russia were mainly distributed in large climatic zones running from southwest to northeast. Indeed, the zonal soil classification of Sibirtzev (1895), the first successor of Dokuchaiev, was principally a soil classification based on climate. But if we study the classifications of both Dokuchaiev and Sibirtsev more closely, we may recognize that, besides climatic factors, they also assign to the natural vegetation, to the soil relief, to the age of the soil, to the parent rock, and to other local factors, equally determining importance in the formation of well-defined soil types. Moreover, they have shown not only that different soil types may be formed from the same parent rock under the influence of differences in climate, but that similar soil types have been formed from very different parent rocks in the same climatic soil zones.

Since the fundamental treatises of the Russian scientists were published only in the Russian language, the international scientific literature did not take notice of them. At about the same period (1892–1894), Hilgard published several papers on the effect of climate on soils, based on his own soil studies. His investigations were not only independent of the Russian school, but they treated quite another field of soil science; he endeavored to indicate the great importance of humid and arid climates in determining the chemical composition of soils and subsoils. He also developed an entirely new school for the interpretation of chemical soil analysis. It is not necessary to emphasize here Hilgard's well-known fundamental researches on alkali soils. He was the first to demonstrate experimentally that the climate of arid regions favors the formation of alkali soils. He made such comprehensive investigations of alkali soils that all students who were interested in the subject considered it necessary to consult his numerous papers and his book on "Soils" (1910) in which he gathered together the valuable results of his experiments. Though he had studied sciences in Germany, as a soil scientist he was a self-made man. He was a pioneer in the reclamation of alkali soils through irrigation and by the use of gypsum; he recommended the cultivation of alkali resistant plants and suggested other treatments for the practical utilization of the soils. He was a great master of true soil science, even though the general conception of soil science as an independent science was still in the embryonic stage of development at the time of his death (1916). He personally took part in the organization of the First Commission of Soil Chemistry during the meetings of the Second International Conference of Agrogeology held at Stockholm in 1910. His brilliant correspondence with the president of this commission indicates that he was a serious and creative student of soils to the end of his life. To him belongs much of the credit for the restoration of soil chemistry to its rightful position in agronomy.

## THE FOURTH PERIOD

It is difficult to state the exact time of the creation of an independent soil science. It has been noted previously that, as early as 1862, Fallou mentioned the idea of an independent soil science. Dokuchaiev considered soil as a natural product of the influences of different soil forming factors on soil material; the product was not primarily determined by its geologic origin nor was it to be considered solely on the merits of its agricultural utilization. This conception indicates that to him soil was as much an object of nature as was a mineral, a plant, or an animal. Hilgard demonstrated by numerous analyses that the composition of a soil can differ greatly from that of the parent rock, and that the characteristics of the soil are greatly affected by the climate. The differences in chemical composition of the arid and humid soils were so striking, and the reasons for these differences were so clearly explained by Hilgard, that his theory spread throughout the scientific world of his time.

These facts may suggest that during this period soil science had already received general recognition as an independent natural science. The scientists mentioned, however, were but single guiding stars. It is a characteristic and an interesting historic tale that Ramann narrates in his paper "Uber Bodenkunde und angewandte Bodenkunde oder Technologie des Bodens" (1905). Upon an occasion when a professor of mineralogy asked him what was the field of his studies, Ramann answered, "I am busy in the field of soil science." The professor of mineralogy then inquired, "Does such a science exist?" "Well, Sir," answered Ramann, "if soil science does not exist yet, it will be created now." Indeed Ramann's vision proved correct. This master of soil science fully understood the reasons why soil science could not attain independence of the related sciences. He attempted to settle the controversies and disagreements. There was, however, little opportunity to bring the interested parties together until the meetings of the First International Conference of Agrogeology, held at Budapest in 1909.

In accordance with the proposal of the Hungarian agrogeologists, Treitz, Timkó, Gull, and Béla de Inkey, the late director Lóczy invited agrogeologists and other soil experts to an international conference on the occasion of the fortieth anniversary of the Hungarian Geological Institute. The principal reason for holding this meeting was to discuss the various systems of nomenclature, classification, and cartography of soils which were in use at that time. The Hungarian Geological Institute was commencing some pedological soil mapping, and there was some disagreement as to the procedure that should be followed. Part of the members of the institute recommended adoption of the soil mapping system of the Prussian Geological Institute. The aforementioned agrogeologists, however, preferred the system of soil surveying used in Russia and Roumania; this method was still unknown in other parts of Europe. During the meeting, the Russian school was represented by Glinka, and the German school, by Wahnschaffe; Ramann served as mediator. Glinka fully developed his point of view and stated in conclusion that agrogeology, or pedology, is the science of the soil; that this science is independent of other

sciences or practical considerations; and that soil nomenclature, classification, and soil mapping should be based entirely upon soil genetics. On the other hand, the partisans of the German school emphasized the practical value of the system used by the Prussian Geological Institute. Seven nations (Germany, Austria, Belgium, Hungary, Italy, Norway, and Russia) were represented by the 88 delegates who attended this first international meeting; two other nations (Sweden and the United States) were also represented through reports which appeared on the program of the conference. Although not all of the points of disagreement could be settled during the meeting, the conference was so successful that it was unanimously decided to assemble again the following year in Stockholm at the occasion of the meetings of the Eleventh International Congress of Geology. The group met, however, not as a section of this congress, but separately as the Second International Conference of Agrogeology. Thus started the general movement to deliberate soil science independently of other sciences and considerations. At Stockholm the scientific discussions were well developed, but it became apparent that some permanent organization should be created. The three following permanent commissions were therefore formed: (1) For study of the mechanical analysis of soils. (2) For study of chemical analysis. (3) For consideration of nomenclature for the soil types of the morainic country of northeastern Europe. These commissions fostered the exchange of ideas, and this service was further extended through the medium of the *Internationale Mitteilungen für Bodenkunde*—a journal founded as the official periodical of the International Conference of Agrogeology. This was published, first, under the editorship of Professor Wahnschaffe and, after his death, under that of Professor Schucht. At about the same time two other journals for scientific reports on soils appeared. One of these was the Russian periodical *Pedology*, in which it was possible to publish articles in languages other than Russian. The second was *Soil Science*, established by Doctor Lipman in America in 1916. Both the German and the American periodicals were continued during the World War and these represented the sole connecting links between the soil scientists for the period. After the war, the three commissions and the three periodicals were the international centers from which the movement for the advancement of soil science was revived. Even at the Third International Conference held in Prague in 1922, there was evidence of great interest. The Fourth International Conference in Rome (1924) had such a large attendance and included so many papers and reports that it appeared similar to a congress. At the instigation of Doctor Hissink, the International Society of Soil Science was established during the meetings in Rome; this has continued to be the official organization for the promotion of soil science.

At Rome another important step was taken in the expansion of this international scientific movement. Doctor Lipman was authorized to prepare for the first meeting of the new society, and he invited the members of the Fourth Conference to attend the First International Congress of Soil Science, which

was held in Washington, D. C., in 1927. The President of the United States extended invitations to the foreign governments to be represented by delegates at this congress.

Many far-reaching results and benefits were derived from the meeting: (1) A large number of American scientists became interested in the society, whereas previously few had participated in the conferences of agrogeology. (2) The delegation of 20 soil experts from Russia had the opportunity to develop in detail the results of the modern Russian school of soil science. (3) Membership in the society reached the unprecedented number of 934. Among the members were scientists from all parts of the world where soil science was receiving consideration.

It is impossible to sketch here, even briefly, the numerous interesting reports and lectures which were presented during the ten days of the Congress. Each of the six commissions and some subcommissions into which the society was now divided, held separate sessions. The organization of these divisions at the time of the Congress was as follows:

1. First Commission: soil physics. President Novák, Czechoslovakia.
2. Second Commission: soil chemistry. President de'Sigmond, Hungary.
3. Third Commission: soil microbiology. President Stoklasa, Czechoslovakia.
4. Fourth Commission: soil fertility. President Mitscherlich, Germany.
5. Fifth Commission: nomenclature, classification, and cartography. President Marbut, United States.
   *a*. Subcommission for the soil map of Europe: Chairman Stremme, Danzig.
   *b*. Subcommission for alkali soils: Chairman de'Sigmond, Hungary.
6. Sixth Commission: application of agricultural engineering to soil science. President Girsberger, Switzerland.

Leading this illustrious group of soil scientists was the president of the First Congress, Doctor Lipman. Previous to the congress he was well known internationally from his studies in the field of soil microbiology and from his editorship of SOIL SCIENCE. During the congress he was distinguished by his remarkable capacity for organization and by his keen sense of diplomacy.

During the organization of the meeting he was aided by a large committee including Doctors Schreiner, Marbut, McCall, and Waksman. Note should also be made of the services of Doctor Hissink, acting president, and of Doctor Schucht, editor of the official review journal.

Since the time of the First Congress many special conferences of the separate commissions have been held in various parts of the world. In 1930, the Second International Congress met in Leningrad and Moscow. At the present writing, preparations are being made for the Third Congress to convene at Oxford during the summer of 1935. The organization for this Congress is as follows:

First Commission. President Robinson, England.
Second Commission. President de'Sigmond, Hungary.
Third Commission. President Waksman, United States.
Fourth Commission. President Prianischnikov, U. S. S. R.

Fifth Commission. President Marbut, United States.

Subcommissions for soil mappings: For Europe; Stremme, Germany. For the Mediterranean countries; del Villar, Spain. For North America; Marbut, United States. For South America; Matthei, Chili. For Asia; Polynov, U. S. S. R. For Australia; Prescott, Australia.

*a*. Subcommission for alkali soils; Chairman de'Sigmond.

*b*. Subcommission for forest soils.

Sixth Commission. President Fauser, Germany.

*a*. Subcommission for the peat soils: Chairman Ogg, Scotland.

It is apparent that soil science, which, according to Ramann, did not exist 30 years ago, is now sponsored by a well-organized scientific society, which compares favorably with similar societies organized in other fields of natural science. Soil science has now become an independent science without losing contact with related sciences and practical interests. Today soil is conceived to be a dynamic system differing materially from the more stable rocks and minerals from which it is formed. The pedosphere occupies a zone on the surface of our globe between the lithosphere, or regolith, and the biosphere and atmosphere. Although soil is not a living body, it is the home of millions of living organisms. The soil is the cradle and the tomb of all organic life.[1]

[1] The historical data were compiled from the following publications:

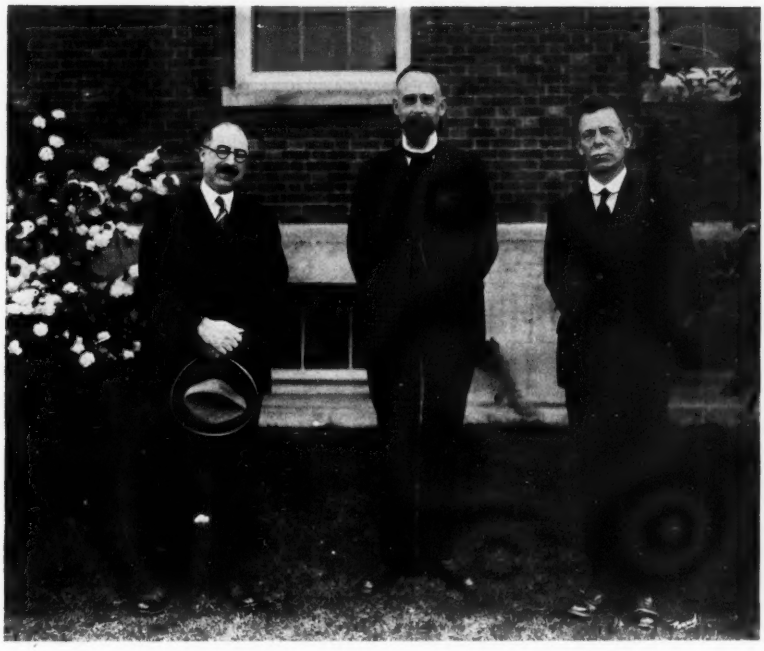
'SIGMOND, E. DE. 1934 Általános Talajtan (General Soil Science in the Hungarian language). Budapest.

'SIGMOND, A. A. J. DE. 1934 Un court aperçu historique sur les premiers dix ans de l'Association Internationale de la Science du Sol. *Soil Res.* 4: 113–124.

'SIGMOND, A. A. J. DE. 1929 Influence de vingt ans de la cooperation internationale sur l'évolution de la science du sol. *Trans. Second Comn. Internatl. Soc. Soil Sci.* (Budapest, Hungary) B: 163–169.

NEUSS, O. 1914 Die Entwicklung der Bodenkunde von ihren ersten Anfängen bis zum Beginn des 20. Jahrhunderts. *Internatl. Mitt. Bodenk.* 4: 453–495.

RAMANN, E. 1913 Bodenkunde. J. Springer, Berlin.



DOCTOR LIPMAN AND TWO PROMINENT VISITORS TO THE EXPERIMENT STATION IN 1927

# THE INFLUENCE OF THE SOIL UPON THE GROWTH OF THE PLANT

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The growth of the higher plants is determined by a series of influences emanating from the surrounding inorganic nature, which may be divided into climatic, atmospheric, and edafic growth factors. Climatic and atmospheric factors include primarily temperature, light, and precipitation, and edafic factors include, above all, the content and the availability of the nutrient salts in the soil. As is commonly known, it is impossible to draw a definite line between climate and soil factors because the former influences the soil with respect both to type and to the prevailing content of nutrient elements, moisture, and microörganisms. One of the projects in soil science is to determine how the climate affects the formation of certain soil types, irrespective of the influence of geological foundations. The most extensive project and the one most important from a practical standpoint is without doubt the research on the ability of the soil types in question to deliver nutrients to the plants. In this research project are combined physical and analytical chemistry, microbiology, and plant physiology.

The absorption of nutrients by plants and their influence on the growth is a plant physiological problem which may be studied most conveniently with water cultures or pot cultures with moistened quartz sand. In such cultures all the salts may be added in solution, and the influence of the concentration of the various elements may be observed. In the soil, however, there is a series of complicated conditions which primarily depend on the soil's content of organic and inorganic colloids and on the relation of the hydrogen-ion concentration to the solubility of phosphates and carbonates of Ca, Mg, and Fe. A good guide in the application of the results of plant physiological experiments to field conditions is the observation of the *absorption* of nutrients. Formerly the investigator limited himself too closely to looking for a direct relation between plant growth and the absolute amounts of nutrient elements present in, or added to, the soil. It is clear, however, that the physiological effect of one nutrient element depends only on its quantity or concentration within the plant. The rate at which a nutrient element is absorbed is not always in direct proportion to the outer concentration. Ionic antagonism may result in important changes in the relation between outer and inner concentrations. Quantitative ash analyses, therefore, are fundamental to the knowledge of the effect of nutrient elements on growth and yield. For the nitrogen assimilation, moreover, other forms of analysis are necessary.

Thorough investigations by several scientists, among whom Hoagland may be mentioned as one of the earlier ones (7), have shown definitely that elements taken up by the plants through the roots are not absorbed in stable combinations, i.e., as neutral salt molecules, but as anions and cations, whereas the relations between the incoming ions are determined partly by their chemico-physical qualities (charge, volume, etc.) and partly by the energy potential that exists between the protoplasm and the surrounding medium and that is maintained by the life processes, mainly the respiration.

The term "ionic absorption" must not be interpreted to indicate that an anion or a cation enters a cell without the simultaneous release of one equally charged particle from the cell. Such a thing would be impossible, since the ions are strongly electrically charged and any such disturbance of the equilibrium would lead to an immediate discontinuation of the uptake of ions. The concentration of anions remains equal to that of the cations in the nutrient medium, an ion absorption, therefore, always includes an ion exchange between the medium and the living cells. Besides the ion exchange, however, the uptake of undissociated molecules may play a rôle, e.g., in the absorption of $NH_4OH$ at higher pH values (15) or in the uptake of $Si_2O_2$ (9).

If a root system is submerged in a pure solution of, for instance, KCl, then as a rule more K ions than Cl ions are taken up while the hydrogen-ion concentration increases correspondingly. In a solution of $Ca(NO_3)_2$ generally more $NO_3$ ions than Ca ions are absorbed and the concentration of OH or $HCO_3$ ions increases to a corresponding degree. The ion absorption, therefore, simply may be thought of as an exchange of cations for H ions and of anions for OH or $HCO_3$ ions between the nutrient medium and the root system. The ion absorption nature of the exchange may be shown in pure salt solutions, where to a certain extent Na, Ca, and K ions are given off from the roots, in exchange for the cations taken up. The varying exchange capacities of Na, K, Rb, Cs, or Ca, Sr, and Ba also are reflected clearly in the different quantities of cations which are forced into the substratum by those previously mentioned (13). Quantitatively, however, the H ions dominate as exchange ions among the cations, since they are produced in unlimited quantities through the respiration processes. The same is true for the anions, OH and $HCO_3$.

That the living cell must develop a certain amount of energy during ion absorption is shown by the fact that salts usually accumulate in the cell in higher concentration than in the surrounding medium. The absorption potential in this case may be looked upon as a lever for the ion absorption, but the potential level must be maintained, which in turn requires energy. It has been shown that a definite relation exists between respiration and the amount of anions absorbed, according to the formula

$$R_t = R_g + k \cdot A,$$

where $R_t$ = the total respiration, $R_g$ = the strictly aerobic fundamental respiration ("Grundatmung"), and $k \cdot A$ = the additional facultatively anaerobic

anion respiration, which is governed by the amount $A$ of absorbed anions; $k$ is a coefficient characteristic for each anion (12).

We go further, then, to look at the relation between the concentration of one nutrient element in the substratum and its concentration in the plant. In a pure solution of a nutrient salt the amount of absorbed anions and cations will increase with the outer concentration along a logarithmic curve. If, on the other hand, the solution contains two or more salts simultaneously, usually antagonistic phenomena occur which may change the relation between outer and inner concentration. Ionic antagonism lies in the presence of an ion, e.g., Ca, which will retard the intake of another ion, e.g., K. According to investigations by Burström (1) the extent of the retardation is a function of the interrelation of the concentrations of the two elements affecting each other. It occurs to some degree primarily when the concentrations (in equivalents) of the two elements are about equal and soon reaches its maximum when the concentration of the retarding ion is larger than that of the one being retarded (fig. 1). Burström has found a colloid chemical parallelism to this phenomenon, and thus the theory that ion adsorption and ion exchange form a lever for the salt uptake by the roots is further strengthened. The antagonism K:Ca and Ca:K is of particularly great importance.

Many experiments with water and pot cultures have been performed by plant physiologists and agricultural chemists to determine the importance of nutrient ions to the growth of plants. These experiments have shown, in general, that when one nutrient element is increased with respect to the others an increase in growth occurs which is nearly proportional to the increase in the concentration at the minimum levels but which becomes relatively smaller with higher additions. In the case of very high additions, a decrease in growth has often been established. A number of German workers, Mitscherlich (16) among others, have attempted to trace the growth curves by means of mathematical formulas. The value of such formulas, however, at least from a practical standpoint, is diminished by the fact—as has been shown by Rippel (19) and others—that the effect of every nutrient element depends on the quantity of the other elements present at the same time. Rippel found that with a high content of nitrogen in the soil the effect of potassium on the growth is smaller than with a low content of nitrogen. Here again is an interaction between growth factors somewhat similar to ionic antagonism, although in the present case it may be founded on certain metabolic phenomena. As a proof of the particularly complicated relation between the growth factors and the growth it may be mentioned here that Shive in his extensive trials with water cultures has found that most satisfactory growth can be obtained in solutions of varying composition.

In connection with pot cultures in quartz sand carried out in the author's laboratory, complete ash analyses have been made by means of which the growth produced could be correlated with the inner ion concentration and ionic balance. We shall limit ourselves here to a discussion of the cations K, Ca. Mg, and Mn.

The relation between cation content per unit dry weight and growth produced is most obvious for K (fig. 2). The growth increases uniformly with the inner potassium content up to an optimum, above which larger K contents have little effect. No distinctly injurious effect from the surplus of K (up to 2,200 millimols per kilogram dry weight in the leaf tissues of oats) has been observed. For calcium, at low contents the growth increases very fast with increasing inner Ca content. An optimum is obtained at a relatively low Ca content

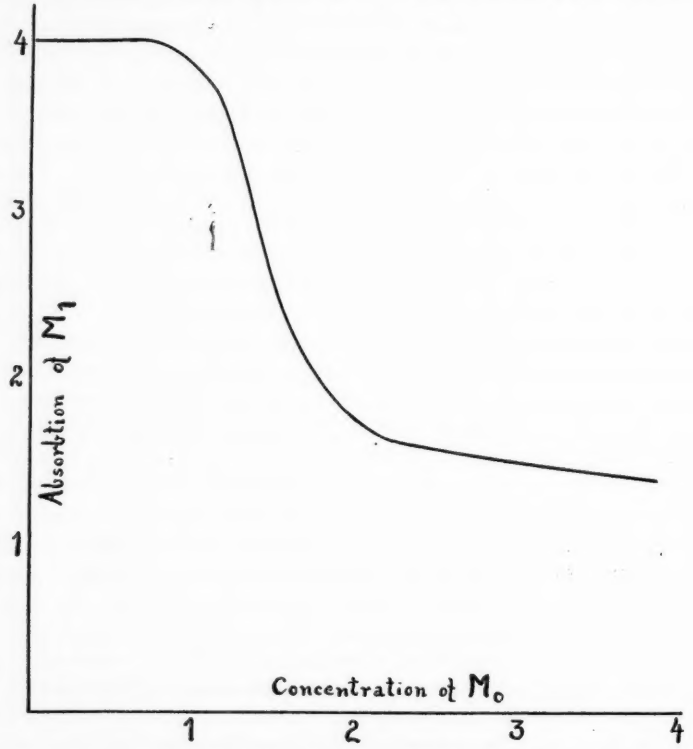


FIG. 1. DIAGRAM OF THE ANTAGONISTIC ACTION OF ONE ION ($M_0$) ON THE ABSORPTION OF A SECOND ION ($M_1$)

At the figure 1 on the abscissa the concentrations of $M_0$ and $M_1$ are equal. $M_1$ is constant during the experiments; $M_0$ is varied. The concentrations are in equivalents (1)

(44 m. mols./kgm.) and only at high Ca contents (above 225 m. mols.) do retarding effects occur. Magnesium acts very similarly, although injurious effects have not necessarily occurred. It appears that exceptionally small amounts (less than 1 m. mol./kgm.) of manganese, which seems to be a necessary nutrient element for oats, produce some effect, but, on the other hand, an injurious effect from a surplus of Mn in the tissues (up to 20 m. mols.) has

not been established. This observation may have some connection with the fact that Mn as well as Fe and to a certain extent also Ca and Mg are bound into insoluble compounds in the tissues.

These briefly related investigations show very clearly the importance of a correct balance between the various ions in the nutrient medium. This fact has already been pointed out by Hansteen-Cranner (5), Osterhout (17), and others, although these workers have not taken into consideration the *inner* ionic balance in the plant, which naturally is the actual cause of the effects on growth. In spite of a medium outer supply of Ca, because of the ion antagonism, a lack of Ca within the plant may occur in the case of an extremely high outer K

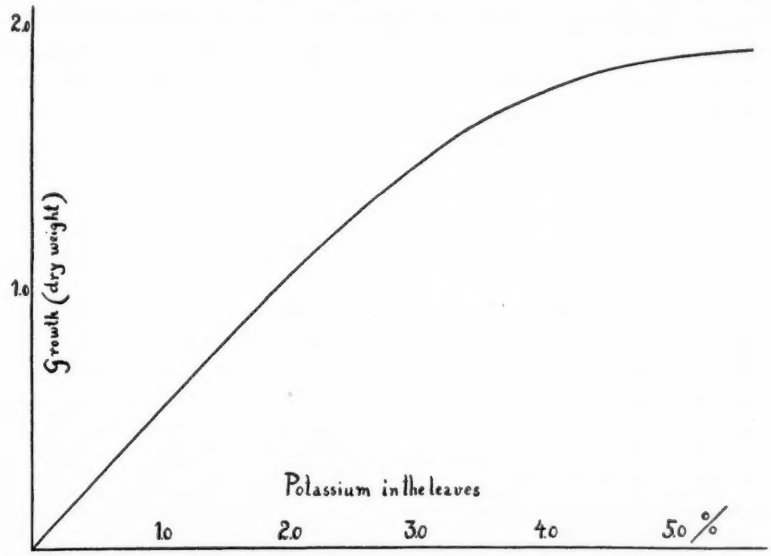


FIG. 2. THE RELATION BETWEEN THE INNER CONCENTRATION OF POTASSIUM IN THE LEAVES OF OATS AND THE GROWTH (9)

concentration. Conversely, at a low outer K concentration even a modest Ca concentration may result in an injurious surplus of this element in the tissues. Similar antagonistic effects in the case of ion absorption occur between K, Mg, and Na and between Ca, Mg, and Mn. $NH_4$ also retards the Ca intake (1).

The ion antagonism appears primarily as a surface effect between the medium and the roots and is to be considered as an adsorption substitution of the same kind as the substitutive relations between an inorganic gel with powerful adsorption ability and a solution of neutral salts. The antagonism is strongest between the outermost ions in the adsorption series Mn > Ca> Mg > K > Na (1).

Since, however, the mobility of the ions in a colloidal medium, and thus also

in the plant tissues, is a function of the charge and diameter of the ions, the very mobile K ion will be translocated in the plant much faster than, for instance, the less mobile Ca ion, in which case at an equal outer concentration of these two elements much more potassium will be taken up than calcium. In this case the antagonism *within* the plant of K:Ca will soon dominate. Also the translocation of the ions within the plant is affected by the colloidal chemical character of the protoplasm. Thus potassium to a certain extent favors the translocation of other ions, whereas the presence of calcium retards it (1).

The anions are pulled into the metabolism to a greater extent than are the cations, but a certain luxury absorption, in particular of Cl, might be of importance in facilitating the cation absorption. Here the chemico-physical characters of the anions come into effect. The very mobile $NO_3$ ion is a favorable factor for cation absorption; Cl and particularly $SO_4$ are less mobile; and $H_2PO_4$ seems to be fairly mobile.

These plant physiological and chemico-physical facts briefly touched upon form the background against which we must look at the problem of the influence of soil on plant growth. As has been mentioned, there is no marked difference between the nutrient uptake from a soil and from a nutrient solution. Certain important differences which present themselves, however, are mentioned in the following.

In the soil the roots of the plants are not freely floating in the soil solution, but the root hairs serving as absorption organs adhere to the humus particles, the clay coagulates, or the colloidal membranes of the mineral particles. Instead of the free and unobstructed supply of ions in a solution we are confronted with a kind of ion transport in a colloidal medium; moreover, the soil colloids mostly have a powerful buffering effect against changes in the reaction. Finally, most of the nutrient substances are not entirely dissolved but are present as adsorption fixations or as chemical compounds, the solubility of which usually is closely related to the hydrogen-ion concentration.

With respect to the direct effect of the soil colloids on the ion absorption, experiments carried out in the author's laboratory, where colloidal humus or $SiO_2$ gel has been added to the substratum (ground quartz), have shown that the uptake of the bivalent Ca, Mg and Mn is retarded; this is analogous to the conditions in case of an ion transport within the plant. Probably here also a certain adsorption competition occurs between the colloids of the soil and those of the roots.

Thus, the importance of the buffering effect is clear if we consider that any deviation from the equivalence relation between the cations and anions absorbed is followed by a certain loss of energy by the cells. A one-sided anion absorption (for instance from Ca $(NO_3)_2$) may be compensated in a solution to a certain extent with a profuse $CO_2$ outgo (11), provided the aeration is not too strong. If, however, the soil is well buffered against an increase in the pH value, this becomes a valuable aid to the anion absorption. Conversely, a

buffering against a lowering of the pH value facilitates a one-sided cation intake. Thus in a well-buffered soil the ion absorption can accommodate itself more readily to the plant's immediate need of the various ions. This is probably one of the explanations of the superiority of the neutral colloidal soils as growing media. To this may be added the large quantities of exchangeable cations which are readily available.

The factors determining the solubility conditions in the soil are of great importance. Thus, for instance, the activity of carbonates and phosphates of Ca, Mg, and Fe and of Mn compounds is very closely related to the actual pH value. Investigations of the solubility of phosphoric acid have been made by Gaarder (4) and others. The following data (9, p. 167) from a pot culture series with lime may serve to illustrate the solubility versus the pH value:

| pH value of the pot culture solutions | 5 | 6 | 7 |
|---|---|---|---|
| Soluble P in mgm./liter | 25.1 | 20.3 | 12.7 |
| Soluble Ca in mgm./liter | 848.0 | 443.0 | 387.0 |

In a similar way the solubility of Mg, Fe, and Mn compounds is influenced by the hydrogen-ion concentration. The solubility of Mn, however, increases with an alkaline reaction. With respect to phosphorus compounds it should be pointed out that certain organic esters are available at higher pH values. Mn and Fe take part to a certain extent in the oxidation and reduction processes in the soil.

The importance of the hydrogen-ion concentration to plant growth, however, is not limited to its relation to the solubility of a number of nutrient elements; the speed of absorption bears a definite relation to it also. For chemico-physical reasons the absorption of cations is favored at an alkaline reaction, and that of anions, at an acid reaction. It has been possible to establish this fact in physiological experiments, e.g., with $NH_4NO_3$ (2) or in the case of K and $H_2PO_4$ in the soil (10). Certain trials, however, seem to show that the bivalent elements Ca and Mg act differently, i.e., they are absorbed in greatest amounts at a reaction approaching neutrality (9). These conditions, though as yet insufficiently studied, should be included in a discussion concerning the relation of pH to plant growth. Moreover, it should be pointed out that according to experiments by Prianischnikow, the author, and others (18, 8) the ion antagonism between H ions and Ca ions, which latter thus will counteract the unfavorable influence of higher concentrations of $H^+$, has a definite effect.

In the literature we find analyses representing averages only of the nutrient absorption under natural conditions, whereas the knowledge of the varying influence of the different soil conditions usually is limited to yield data. However, in this case only careful analyses will give information on nutrient substances absorbed in relation to nutrients present in the soil in order to estimate the plant's ability to utilize different soil types. Such parallel analyses of soil and crop have been carried on at the author's laboratory, and so far several

series have been completed, including several hundred cases of oats and sugar beets in Sweden (10). The method employed involves *triple analyses*, made in such way that before the crop reaches maturity samples are taken from the still green leaves, from the soil around the roots, and from the subsoil directly beneath the plant. These samples are later analyzed for K, Na, Ca, Mg, P,

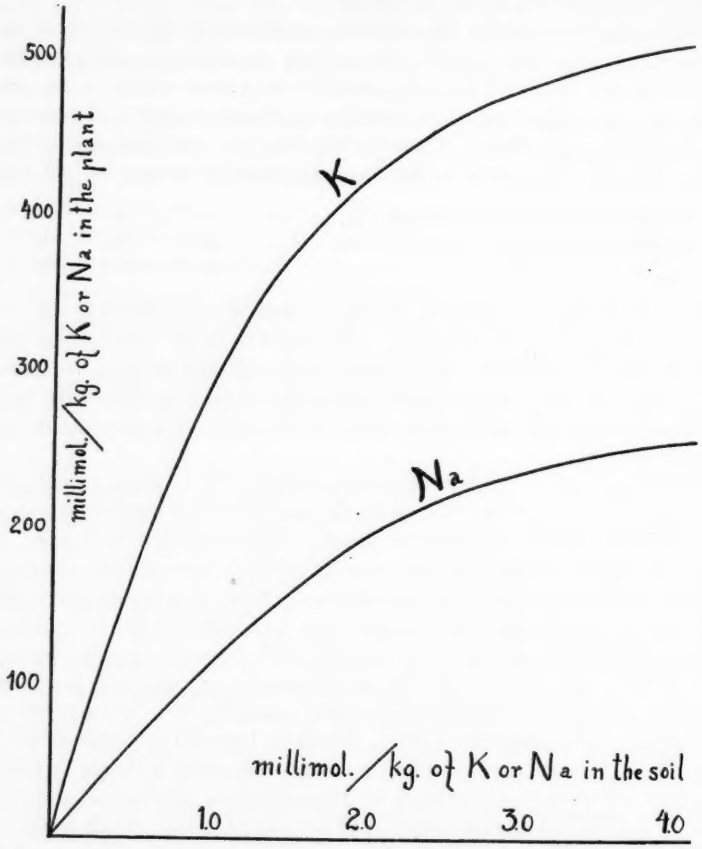


FIG. 3. THE RELATION BETWEEN THE AMOUNT OF AVAILABLE POTASSIUM IN THE SOIL AND ITS CONCENTRATION IN THE PLANT (OATS)

From triple analyses of more than 300 fields in different parts of Sweden (10)

and Mn. The results of the analyses are expressed in millimols per kilogram soil, and per kilogram dry plant matter respectively. A 2-per cent solution of citric acid is used for the soil extracts.

A compilation of analyses of oats with soil analyses in this connection (in this case referring to the surface soil) shows that the alkali content in the

plant increases regularly with the alkali content in the soil, irrespective of the soil type (fig. 3). The absorption of calcium and magnesium at first increases rapidly also with the amount in the soil, but at higher concentrations in the soil an optimum is obtained, and at very high concentrations, conversely, the absorption is somewhat retarded (fig. 4). The manganese absorption is somewhat similar, but the phosphorus intake proved to be rather independent of the content found in the soil extracts. For Ca and Mg, it might be sufficient

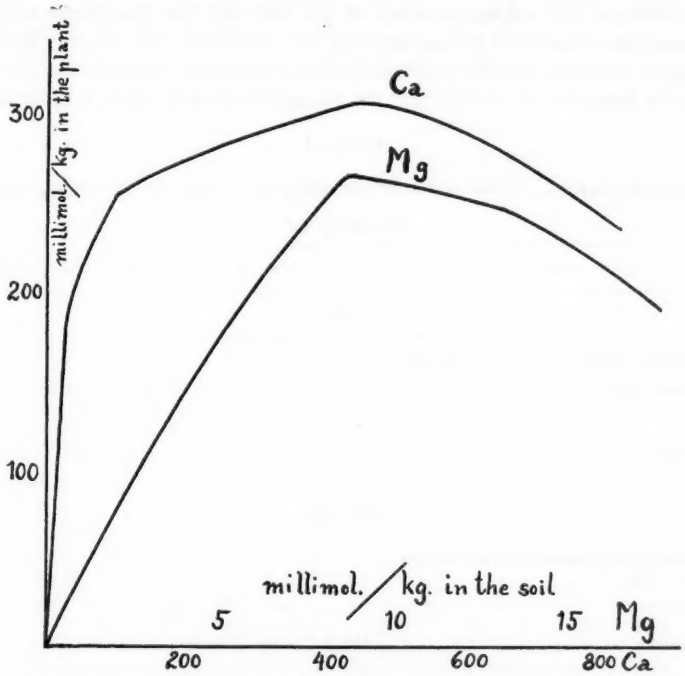


FIG. 4. THE RELATION BETWEEN THE AMOUNT OF CALCIUM AND MAGNESIUM IN THE SOIL (FROM EXTRACTS WITH CITRIC ACID) AND THE CONCENTRATION OF THESE ELEMENTS IN THE PLANT (OATS)
From the same fields as in figure 3 (10)

to refer to the diminishing solubility with increasing contents. The pH value increases regularly with the Ca content, and Ca and Mg as a rule are present in a definite relation to one another in the soil. Also physiologically the absorption of Ca and Mg shows a decrease on the alkaline side. In general, field observations agree well with the theoretical premises.

The quotient $\frac{V\ (=\text{percentage in vegetation})}{S\ (=\text{percentage in soil})}$ expresses the rate of intake for the various elements (table 1). At comparable contents in the soil for the

oats, a series K > Na > Mg > Mn is obtained, which agrees with results from water cultures.

With increasing content of one element in the soil, naturally the quotient $\frac{V}{S}$ is lowered. Table 1 includes the average contents of Swedish soils.

The triple analyses bring out also other agreements between the field conditions and the laboratory experiments. Thus there is a definite relation between the calcium content of the soil and the manganese intake, irrespective of the total Mn content (fig. 5). At higher lime content the Mn intake is retarded, and the gray speck disease on grains appears. Investigations by Burström (1) showed that the antagonism of K:Ca appears primarily

TABLE 1

*Values of the quotient $\frac{V}{S}$ for oats and sugar beets (green leaves) at the normal content of salts in the surface soil*

| ELEMENT | K | Ca | Mg | Mn | Na | P |
|---|---|---|---|---|---|---|
| *Oats* | | | | | | |
| Percentage of element in the soil in millimol/kgm | 1.0 | 50.0 | 1.5 | 0.5 | 1.0 | 1.0 |
| Quotient $\frac{V}{S}$ | 332.0 | 3.4 | 35.0 | 3.5 | 116.0 | 114.0 |
| *Sugar beets* | | | | | | |
| Percentage of element in the soil in millimol/kgm | 1.0 | 50.0 | 1.5 | 0.5 | 0.5 | 1.0 |
| Quotient $\frac{V}{S}$ | 815.0 | 6.6 | 271.5 | 3.8 | 991.5 | |

at the equilibrium between K and Ca concentrations. Because of the generally low content of potash in Swedish soils usually no antagonism of K:Ca is noticed. Only in sugar beets, which are known to have a large absorption of alkalies (table 1), can the antagonism be noticed. On soils with low Ca content the antagonism of K:Ca may be easily effected by potash fertilization. Thus it is of importance, in the case of a potash minimum, to supply enough of this material to prevent a calcium surplus in the tissues, from which follows a decrease in growth. For normal development of oats, values of the quotient K:Ca in the leaves of about 1.5–5.0 are required. Too low or too high values are tied up with pathological symptoms. In order to obtain the normal quotient K:Ca the Ca content of the soil should be approximately 50 times greater than the K content.

Recently, with increasing interest, much study has been devoted to those elements in the soil which are present in rather small quantities (Mn, Cu, B, etc.) but which nevertheless have a definite influence on plant growth. The importance of manganese has already been pointed out, i.e., it is indispensable for normal development of oats and beets and of some other cultivated plants. The quantity required, however, is very small (about 0.1 millimol/kgm.). The average content of extractable manganese in Swedish soils is 0.5 milli-

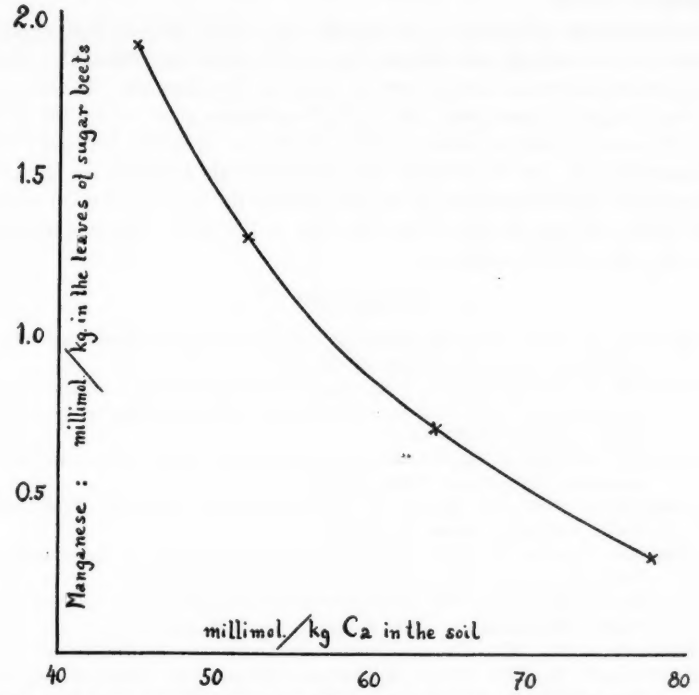


FIG. 5. THE INFLUENCE OF THE CALCIUM CONTENT IN THE SOIL ON THE UPTAKE OF MANGANESE IN SUGAR BEETS
From a field with great variation in the Ca percentage

mol/kgm. but in some individual cases there is a lack of manganese. The unfavorable effect of higher lime content on the manganese intake can be counteracted by the addition of sulfate of ammonia, which will lower the pH value and make the manganese active.

With respect to boron, there are a number of investigations, among which may be mentioned those by Warington (20). The presence of boron seems to favor Ca absorption. This question, however, requires further extensive investigations. The importance and effect of Cu are still less known. Unpublished

data from the author's laboratory show that several metallic ions, such as Cu, Co, Pb, Tl, Hg, have a remarkable effect on the cell mechanism and at even very low concentrations may retard the anion absorption. Very small amounts of, for instance, Cu will stimulate the fundamental respiration. These last mentioned elements, which are active even when present in very small quantities, seem to take part in the enzymatic processes in the protoplasm in a far different way from K, Ca, and Mg and thus very differently affect the progress of growth.

Certain specific influences on the growth may also be derived from organic substances present in the soil or formed through biological processes (3). More recent investigations on auxines seem to point in this direction. In this connection it might be mentioned also that phosphatides given off by the roots normally seem to bear a definite relation to the ion exchange between roots and solution (13). In the soil these phosphatides might influence the microörganisms (14), and it is perhaps not impossible that the thriving of other plants in the same soil may be affected by this work of the roots. These questions, however, are not yet worked out.

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# THE AGRONOMIC IMPORTANCE OF CALCIUM

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Among the elements that are essential to the growth of plants, nitrogen, phosphorus, and potassium have long been specially emphasized by agronomists. Soil fertility has come to be regarded as chiefly a matter of available nitrogen, phosphate, and potassium. The fertilizer industry and fertilizer practices have been developed largely on this assumption. Although there is no reason to doubt the importance of these three elements, researches in the field of soil science have shown that too little emphasis has been placed on calcium, for we now know that calcium in soils performs several functions that are of the greatest agronomic significance. The importance of calcium may be considered from the standpoint of soil acidity, plant growth, phosphate availability, soil structure, soil formation, alkali soils, and the use of fertilizers. The calcium content of plants, which is influenced to some extent by the supply of available calcium in the soil, also plays certain highly important functions in animal nutrition.

*Calcium in relation to soil acidity.*—Formerly, soil acidity was thought to be due to soluble substances, chiefly organic. We now know that this is only a minor aspect of the question. The acid substances of soils are, for the most part, not soluble in the ordinary sense, rather they are colloidal in nature and they are both organic and inorganic. Non-saline neutral soils are usually approximately calcium saturated, that is, calcium is the dominant exchangeable cation. Under leaching conditions, the calcium becomes replaced by H ions from the surface of the colloidal particles. In consequence, these particles become acid. As the intensity of the replacement of Ca ions by H ions increases, the inorganic colloidal particles tend to become chemically unstable and this leads to two consequences: (*a*) Silica becomes split off from the inorganic base-exchange substances, with the resulting formation of clay-like substances having a low silica-alumina ratio and reduced base-exchange capacity. (*b*) Aluminum comes into play as an exchangeable cation. The remedy for soil acidity is lime; this fact, of course, has long been recognized, but the action of lime is not merely that of a neutralizing agent. The application of lime restores calcium to its place on the colloids and this produces significant effects on various properties of the soil.

The inferior growth of legumes, often noted on acid soils, is not necessarily caused exclusively by excessive concentrations of H ions as such, or by soluble aluminum. Inadequacies in the available calcium supply may be equally as important and in certain cases even more potent. Highly acid soils are usually

deficient in available calcium, and this deficiency is not overcome merely by reducing the H-ion concentration of the soil. That calcium is leached out of decomposing rocks and soils in great quantities was pointed out many years ago by F. W. Clarke in his discussions on the composition of the waters of natural streams. It remained for soil scientists, however, to show the agronomic importance of this process.

*The relation of calcium to plant growth.*—As has been indicated, inadequate supply of calcium in acid soils is often an important factor in the growth of legumes. When grown on such soils, those species of legumes that normally absorb relatively much calcium are often found to contain somewhat subnormal amounts of calcium. Certain important microbiological soil processes are also adversely affected by inadequate calcium supply and by soil acidity. For example, both the symbiotic and certain non-symbiotic nitrogen fixing organisms do not function normally in highly acid soils. This in turn becomes reflected in the growth of higher plants. The development of the root system of plants, both leguminous and non-leguminous, may be greatly influenced by the available calcium supply. For example, when the concentration of calcium falls below a critical level the roots of orange trees manifest pronounced abnormalities; in fact, calcium plays a highly important rôle in the growth of the roots and other parts of several species of citrus and other plants. Calcium also affects the growth of plants through its influence on the absorption of other elements. Within certain limits, an inverse relationship has been found between the absorption of calcium and potassium by plants. Calcium affects the toxicity caused by high concentrations of magnesium and sodium probably largely because of its influence on the absorption of these elements. Through its effect on the pH of the soil, $CaCO_3$ may so reduce the solubility of iron in the soil as to produce chlorosis in several different species of plants.

The calcium content of plants, which, as has been stated, is influenced by the availability of the calcium in the soil, has an important influence on their nutritive value as animal feeds. For instance, livestockmen have come to recognize that alfalfa from certain localities is more nutritious than that from others. It is highly probable that the calcium content of the alfalfa is at least one factor in such cases. There are, of course, other factors, such as the phosphorus content of the feed. In the development of the bones of animals and the shell of eggs, calcium plays an indispensable and highly important rôle. In the case of growing children and in certain types of human disease, the importance of the calcium content of the food is widely recognized by physicians.

*Calcium in relation to phosphate availability.*—Generally speaking, a high percentage of the phosphorus of calcium-saturated soils is likely to be available. When soluble phosphate is applied to such soils, it becomes absorbed, that is, fixed, but the fixation of the phosphate is not so extreme as to render the applied phosphate entirely unavailable to the roots of growing plants. On

the other hand, the phosphate of calcium-deficient acid soils is often found to be relatively unavailable, even though the total content of phosphate is comparatively high. Moreover, a considerable part of the phosphate that is applied to highly acid soils tends to become so firmly fixed as to be largely unavailable to growing plants. These facts have not been fully explained. It seems probable, however, that the formation of insoluble phosphates of iron or aluminum is a factor in acid soils, whereas in calcium-saturated soils the phosphate tends to combine with calcium, and hence be more available, since the calcium phosphates are more soluble than the phosphates of iron and aluminum.

However, with soils which contain excesses of $CaCO_3$ the Arizona investigators have suggested that soluble phosphates tend to become converted into carbonato-apatite, which is relatively unavailable to plants. At any rate, the availability of phosphate is sometimes low in soils which contain excesses of $CaCO_3$.

*Calcium in relation to soil structure.*—The state of granulation or coagulation of the colloids of a soil markedly influences the tilth of the soil. The kind and relative proportions of the different cations that are combined with, or absorbed on the surface of, the colloidal particles, largely determine the state of granulation of the colloids. Calcium-saturated colloids are usually not highly dispersed; rather they tend to form aggregates. The state of aggregation of soil colloids is closely related to the tilth of the soil. Moreover, carbonic, nitric, and sulfuric acids that are formed in soils by the biological decomposition of organic materials combine with $CaCO_3$, if present, or the H ions of these acids replace calcium from the base-exchange materials. The soluble calcium salts thus formed increase the Ca-ion concentration of the soil solution and this in turn influences the porosity of the soil by virtue of the pronounced coagulating power of Ca ions. Thus it follows that calcium performs important functions in soil physics.

*Calcium in relation to soil formation.*—As long as the upper horizons of a soil contain $CaCO_3$, the dominant exchangeable cation of non-saline soil will be calcium. Under this condition pronounced segregation of the particles of the soil, with the consequent development of dense subsoil horizons, does not take place, because Ca-saturated colloids are not highly dispersed, but under the leaching conditions of humid regions, $CaCO_3$ is gradually dissolved and leached out of the soil. This is followed by the replacement of calcium by H ions from the colloids with the consequent production of a dispersed condition of the colloids. The result is the gradual development of dense subsoil horizons. The Putnam series of soils affords a good illustration of the results of this process.

In the initial stages in both the podzolization and lateritization processes, $CaCO_3$, when present as a constituent of the parent materials, is first leached out of the soil, followed by the replacement of calcium by H ions from the soil colloids. This tends, as has been stated, to produce a dispersed condition of

the colloidal particles, but as long as the colloids remain calcium saturated, neither true podzolization nor lateritization takes place. Under comparatively cool temperatures, especially when accompanied by forest cover, the dispersed H-clays that are formed become elutriated downward into the subsoil horizons. The result is, the A-horizon of podzols becomes depleted of absorptive materials. The soil is said to be degraded. Under the high temperatures characteristic of lateritization, on the other hand, the H-clays undergo decomposition with the gradual removal of $SiO_2$ and the accumulation of sesquioxides in the upper horizons. Thus it follows that calcium is definitely related to certain important soil-forming processes. The importance attached to calcium in soil-forming processes has led Marbut to propose a broad classification of soils on the basis of their content of $CaCO_3$. If the foregoing reasoning is sound, it would seem more logical to place the emphasis on the degree of Ca-saturation of the soil colloids.

*The relation of calcium to alkali soils.*—Just as H ions replace calcium from soil colloids under humid conditions, with the formation of an acid condition in the soil, sodium tends to replace calcium under arid conditions, with the formation of alkaline conditions. Formerly, an excess of soluble salts was considered to be the most important abnormality of alkali soils. We now know, however, that alterations in the colloidal constituents of the soil, brought about by the replacement of calcium by sodium, are also important, and in certain cases even more important than the soluble salts themselves. The replacement of calcium by sodium, incident to the accumulation of a high concentration of sodium salts, leads directly to significant changes in the physical, chemical, and biological conditions of the soil. The sodium-saturated-exchange substances become highly dispersed when leached, and they undergo hydrolysis with the formation of sodium hydroxide. The net result is a condition extremely unfavorable, both physically and chemically, to plant growth. These adverse physical and chemical conditions are not overcome merely by leaching out the excess of soluble salts. Rather, they are intensified, as a result of the increased tendency toward dispersion and hydrolysis that is brought about by the removal of soluble electrolytes.

Just as in the case of acid soil, the remedy for a sodium soil is calcium. Soluble calcium is able to replace the sodium, thus converting the colloids into a state of calcium saturation, which leads at once to biologically favorable physical and chemical conditions in the soil.

Thus soil science has established a fundamental similarity between acid soils and certain important types of alakli soils. In both, the colloids have become impoverished in calcium. In the case of acid soils the calcium, as has been stated, has been replaced by H ions, whereas with alkali soils calcium has been replaced by sodium, but in the treatment of both, the objective should be to restore calcium to its position on the soil colloids. However, in addition to differences in pH and in the replaceable bases, there is another important difference between acid soils and alkali soils, namely, the latter commonly

contain an excess of $CaCO_3$, despite the fact that the colloids are largely saturated with sodium; whereas, acid soils do not contain $CaCO_3$. The practical treatment of alkali soils in which $CaCO_3$ is an important constituent should be such as to increase the solubility of the native $CaCO_3$. Researches in the field of soil science have shown that the oxidation products of elemental sulfur and of organic matter in general, can be caused to accomplish this end.

When a Na-saturated soil is subjected to prolonged weathering under leaching conditions, the colloids, being highly dispersed, undergo translocation downward, thus producing dense sub-soil horizons. According to Gedroiz, the colloidal alumino silicates may also sustain pronounced decomposition under these conditions. Therefore, the base-exchange materials of the soil are not only removed from the upper horizons of the soil, but also become more or less decomposed. In a word, the evolution of an alkali soil may entail its degradation, somewhat like that of podzolization. However, this degradation of an alkali soil can take place only if the soil is practically free from $CaCO_3$, since, in the presence of $CaCO_3$, Ca ions will replace sodium from the colloids with the consequent formation of flocculated and chemically stable Ca-saturated colloids. Likewise, podzolization does not take place in the presence of $CaCO_3$.

*Calcium in relation to base-exchange capacity.*—Soil scientists hold generally that the base-exchange capacity of a soil is one of its fundamental characteristics. Broadly speaking, base-exchange capacity is a function of two variables, namely, the quantity of certain types of substances present and the kind of such substances. The quantity of inorganic base-exchange substance in a given soil is probably more or less independent of calcium, being largely determined by the content of clay, but its quality appears to be related to calcium. For example, several lines of research have shown that the kinds of clays prevailing in different types of soils differ substantially. Clays related to beidellite appear to predominate in the chernozems and related soil types, and also in immature types of soil such as Yolo, whereas kaolinitic or halloysitic clays seem to predominate in highly weathered soils such as the Cecil and Redding. This is probably true whether the clay has been formed from granitic or basic rocks. Unpublished researches in the writer's laboratory support this view.

It seems probable that the clay minerals that are formed in the comparatively early stages in the weathering of igneous rocks are related to beidellite or montmorillonite. The dominant exchangeable cations of these clays are calcium and magnesium; their base-exchange capacity is relatively high. On the other hand, when these clays, or the soils in which they occur, undergo prolonged weathering, H ions replace calcium and magnesium from the surfaces of the clay particles. The H-clays thus formed are less stable, chemically, than the Ca-forms. In consequence, $SiO_2$ gradually splits off, with the resulting formation of clays resembling halloysite or kaolinite, both of which have low base-exchange capacity.

Ca-saturated clays of high silica content are more stable than H-clays, not only chemically, but physically also. The relatively high dispersability of H-clay promotes its elutriation down into the subsoils by natural precipitation. Therefore, the removal of calcium from the colloids may result in the ultimate lowering of the base-exchange capacity of the soil. Obviously, then, if the foregoing reasoning is sound, the maintenance of high base-exchange capacity in a given soil is conditioned upon its colloids remaining in a state of Ca-saturation. If so, the important areas of soils that are now approximately Ca-saturated should be so managed as to preserve a high degree of Ca-saturation.

*Calcium in relation to the use of fertilizers.*—Finally, the calcium content of a soil, especially as regards $CaCO_3$ and the base-exchange substances, has a direct bearing on the kind of nitrogenous fertilizers that should be applied. The acids formed biologically from ammonium salts tend to produce extremely unfavorable conditions in soils that are low in calcium (for example, Pennsylvania and Rhode Island experiments). But this is not true if the soil contains an abundance of calcium. Ammonium salts are especially applicable where the soil contains significant amounts of $CaCO_3$. It is possible that the solubility of iron and phosphate compounds in calcareous soils may be significantly increased by the application of ammonium salts. However, it is important to bear in mind that the application of ammonium salts of strong acids promotes the loss of calcium from soils generally, and this fact should always be recognized in planning long-time fertilizer experiments or farm practices.

## SUMMARY

The purpose of this paper is to call attention to the rather unusual rôle played by calcium as regards soil acidity, soil-plant interrelationships, soil formation, soil profile development, and alkali soil reclamation. Although the importance of nitrogen, phosphorus, and potassium in soils is not to be minimized, it appears that, from several points of view, calcium is of still greater fundamental significance. The reasons for this conclusion are as follows:

The low pH of acid soils is generally associated with deficiencies in calcium. The function that is performed by liming acid soils is not merely that of neutralization. Liming introduces calcium into the base-exchange material of acid soil. Calcium tends to become lost to soils by leaching, perhaps to a greater extent than any other important cation.

Calcium performs important nutrient functions in plants.

Calcium exerts important influences on phosphate availability and on the absorption of other elements by plants.

Calcium influences the physical properties of soils to a marked extent.

Calcium is related to, and exerts a potent influence on, soil-forming processes.

In arid regions the replaceable calcium of the soil is often seriously displaced by sodium. Certain important types of alkali soils are deficient in soluble calcium because of their high pH and content of sodium salts. The deflocculated condition of black alkali soils is due largely to the replacement of calcium by sodium. The colloids of such soils are analogous to those of acid soils in that both are deficient in calcium. In the treatment of each, the object should be to restore calcium to the colloids. Alkaline compounds of calcium are needed with acid soils, whereas soluble forms of calcium are most effective with alkali soils.

The maintenance of high base-exchange capacity in soils is dependent upon the maintenance of approximate calcium saturation of the colloids of the soil. The so-called degradation of the soil is preceded by the removal of calcium, followed by the removal of the clay and its decomposition. Decomposition of the clays referred to herein, denotes the formation of clays relatively low in silica and calcium, that is, clays analogous to halloysite or kaolinite. High base-exchange capacity, in so far as the inorganic colloids of the soil are concerned, is a property of clays similar to beidellite and montmorillonite. In the development of mature soil profiles in humid regions the exchangeable calcium becomes replaced by H ions.

The degree of calcium saturation of a soil, together with its content of $CaCO_3$, is important in connection with the use of ammonium salts as fertilizers.